

Taking a Leaf from the OPEC Book

In the past few years, governments such as those of Britain and the United States, supported by the multinational petroleum companies, have been ready and eager to complain that they are being held to ransom by the oil-producing countries of the Middle East, now gathered into a formal bargaining cartel known as the Organization of Petroleum Exporting Countries (OPEC). At the same time, the governments of advanced communities find themselves increasingly having to deal with the exploitation of their own mineral resources, and it is now clear that some of them will soon be compelled to follow quite closely in the path which the OPEC countries have pioneered.

The prospect, for example, that from now on the United States will be dependent on imported petroleum is likely considerably to change the United States Administration's attitude towards exploration and exploitation. In Britain, the discovery of oil and gas in the North Sea has turned out to be so much more encouraging than people were supposing even a few years ago that the British government now finds itself compelled by logic and Mr William Hamilton, MP, to make a long overdue reassessment of its policy towards the exploitation of petroleum in the North Sea. In Australia, the forthcoming election is likely to be coloured by persisting uncertainty about the terms on which ore deposits of various kinds should be exploited. And nobody of course will be surprised that governments are consistently starting from the point of view which has given the OPEC negotiations in the past few years their characteristic flavour—that nations with mineral deposits of any kind are anxious to see these exploited in a way that brings the greatest benefit to the communities (or at least to their governments) lucky enough to have commodities to sell. It is nevertheless more than a little puzzling that the developed nations of the world have learned so little from OPEC.

What are the considerations that should determine a government's policy towards the exploitation of the mineral resources in its gift? And what weight should in present circumstances be given to the claims of those who say that so many kinds of mineral deposit are now in danger of extinction that the most urgent need is not to exploit new discoveries of minerals but, rather, to conserve them? Petroleum is, of course, a special but important case, and the focus for the most contentious arguments, partly because consumption continues to grow at between seven and eight per cent a year (for the world as a whole), partly because the cost of exploration is a very large proportion of the expected value of the petroleum recovered from newly discovered deposits, partly because there has recently been a spate of new discoveries of petroleum on the continental shelves of regions hitherto thought innocent of buried hydrocarbons and partly because of the common agreement that liquid petroleum is likely to be one of the most intrinsically scarce of all the raw materials on which modern industry is based. How should the

governments which find themselves blessed with unexpected resources respond to these discoveries? And what should the advanced countries of the world look for in their continuing wrangle with the OPEC countries?

Lessons are to be learned not merely from the way in which the OPEC countries conduct themselves but also from devices like that by means of which the United States has sought over the years to regulate the rate at which domestic reserves of petroleum are consumed. Although regions such as Texas and California have been known for decades to be well blessed with reserves of petroleum, production has been limited by government regulation of the annual yield from the more important oil fields. One result, of course, has been that a large part of the American consumption of petroleum in recent years has come from elsewhere and now, with all the continuing anxiety about the balance of payments in the United States, the point has been reached at which production of domestic petroleum will be increased. It will be recognized that the immediate consequence of the traditional American policy of restricting domestic production has been to increase the price at which petroleum can be marketed, and this of course is what the OPEC agreements also accomplish. And since, of course, the marketing of oil is largely undertaken by multinational companies with every interest to create a buoyant market for their products, the chances are that the prices at which petroleum and petroleum products are now sold are an accurate reflexion of the prices which the oil companies pay for their raw material at the several points from which supplies are obtained.

In making a strategy for the exploitation of newly discovered petroleum reserves, an essential calculation is a forward estimate of what in future will be the selling price of OPEC petroleum. Nations elsewhere will have to recognize that it may be possible to contain the pace at which the price of OPEC petroleum will increase by undertaking to exploit their own domestic reserves as quickly as they can, but that of course implies that their domestic reserves will disappear more quickly, and probably long before the Middle East has no petroleum in the ground. In all the circumstances, it would be prudent if governments outside the Middle East, and the multinational oil companies as well, were to budget for a sustained increase of the price of petroleum in the years ahead. The practical need is, ideally, to ensure that the price of OPEC petroleum is fixed reasonably far in advance.

How should countries such as Britain, which suddenly find themselves blessed with unsuspected reserves of petroleum or of natural gas, seek to make policy in circumstances like these? It must be acknowledged that there is bound to be a conflict between the national interest and the commercial interests of the companies which have been licensed to explore for petroleum in the North Sea, or elsewhere on the European continental shelf. The



companies are understandably anxious to recover as quickly as possible some return on the capital which they have spent on exploration, and so have a vested interest, represented numerically by the interest charges payable on the money spent on exploration, in rapid exploitation. Rapid exploitation is also a potential benefit in a wider sense if there is, for example, a prospect that the price of petroleum sold to industry can in the process be significantly reduced, but it is easy to exaggerate the value of this benefit by forgetting that the cost of fuel is a small and diminishing proportion of industrial costs.

What this implies, for countries such as Britain, is that there may be advantages in more rapid exploration but more deliberate exploitation of the newly discovered domestic reserves. Just precisely where the balance should be struck depends not merely on the price of OPEC petroleum but on the real and substantial costs of arranging that the cost of exploration for new sources of petroleum should not go unrequited for longer than the oil companies would like, which in turn implies that the price of petroleum and its products will be higher than would otherwise be possible, even in circumstances in which newly discovered reserves were big enough to provide a substantial fraction of a country's need of liquid fuel. It is hoped that the British government will have thought this problem out before the time comes to license the next block of territory in the North Sea.

Similar considerations should apply to the strategy for the exploitation of mineral reserves of other kinds. In Australia, for example, the past few years have seen a great spate of new discovery, and Australia has quickly become an even larger exporter of the ores of iron, nickel, copper and the like. Most arguments about the strategy for the exploitation of Australian mineral resources centre around the largely irrelevant question of whether it is in the national interest that the mining companies should frequently rely on non-Australian capital for exploitation of the known reserves. There has been much less discussion of the more important question of how quickly—or slowly—the reserves should be exploited. Moreover, it seems to be assumed that the export of, say, copper ore in return for cash is the most that can be done for the national interests of Australia. In reality, however, it would be much more advantageous if the country could become an exporter not of unprocessed ores but of the corresponding metals or metal products. In short, a more vigorous conservation policy might be married with an economic strategy to yield more national benefit from the reserves now known to exist. This, after all, is the strategy which development agencies are constantly advising developing countries to follow. The OPEC countries have taken the lesson to heart. It is paradoxical that countries such as the United Kingdom and Australia should be so slow to follow suit.

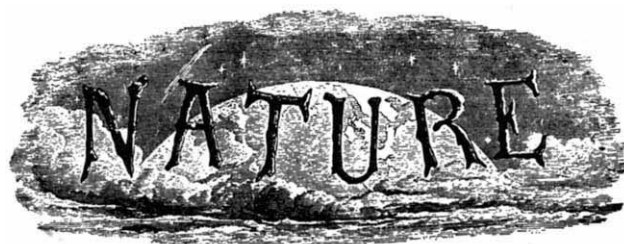
New Instrument Reviews

THIS issue of *Nature* contains the first of what are intended to be occasional reviews of scientific instruments and it is hoped that the scheme will be of value to practising scientists by helping to draw attention to some of the valuable features of new scientific instruments and also to their limitations. The intention is that new instruments should be reviewed much as if they were new

books. In other words, arrangements will be made for an appropriate scientist to have access to a new instrument for a few weeks or even months, and he or she will then be invited to write a brief account of his or her experience with the instrument. But it must be acknowledged at the outset that there are several ways in which the analogy between book reviews and instrument reviews is invalid.

In the first place, because it is intended to deal only with instruments which are truly novel, either because they embody a new technique or an especially clever application of an established technique, reviewers will find themselves on many occasions working with prototypes and not production models. In the circumstances, it may be hard to make the detailed criticism of practical utility on which the success of an instrument may in the long run depend. For this and other reasons, it will also be difficult for reviewers to make the kind of detailed comparisons with other instruments which the zealots for consumerism may look for. A further difficulty is that reviewing scientific instruments in the manner now intended will be possible only with the collaboration of manufacturers, who may be asked to lend a prototype to a reviewer or to suggest how else he might have access to an instrument. Inevitably, manufacturers will be keen to point out the virtues of their new designs and to defend them against the criticisms of the reviewers, so that it will be impractical for instrument reviewers to keep themselves at a distance from the commercial organizations from which their products originate in the sense in which book reviewers keep publishers at arm's length.

100 Years Ago



THE "dead season" has brought up its usual crop of reports of the re-appearance of the sea-serpent, mostly easily resolvable into masses of floating sea-weed. The following extract from an evening contemporary well illustrates the hazy ideas prevalent as to the extinct Saurian monsters of which the sea-serpent is supposed to be a descendant:—"If the sea-serpent continues in its present sociable state of mind, we may perhaps have an opportunity of deciding the vexed question regarding the formation of that portion of his figure which, according to English observers, he keeps concealed under the water. The legend of the Lambton Worm, a popular tale in the North of England, describes the worm as a serpent of enormous size, who used to coil himself round a hill overhanging the River Wear, just as thread is wound round a reel, but a very ancient stone effigy of the creature which lately existed at Lambton Castle, represents it with ears, legs, and a pair of wings. If this effigy was made, as it probably was, from some recollection or recent tradition of the Lambton Worm, these adjuncts would indicate that the beast was one of the winged land monsters which existed at the same time as the *Ichthyosaurus*, but would naturally become an extinct species far sooner than the *fish lizard*, which can conceal itself in the depths of the ocean from the curiosity and violence of man."

From *Nature*, 6, 402, September 12, 1872.

OLD WORLD

British Association meets at Leicester

from our Special Correspondent
THE 134th annual meeting of the British Association for the Advancement of Science got under way at Leicester this week. But not with a bang. Sir Vivian Fuchs's presidential address, lacking as it did the grand pronouncements on science and society that have characterized the inaugural speeches of his predecessors, quietly presented his personal appraisal of the purpose of exploration.

Society, he said, is in danger of stifling initiative by the complexity of the rules which it imposes. Freedom to experiment and explore is being reduced by the development of a community conscience which demands that every error be followed by new restrictions. But exploration must go on. "In what state of knowledge would the human race be now if every rift had been vetoed by the imagined fears of unimaginative little grey men?"

Addressing a far from packed hall, Sir Vivian went on to say that exploration lay now not in discovering new lands but in the scientific exploration of little known parts of the world. Drawing on his own field, Sir Vivian pointed out that there is still much to learn about the polar regions, for example, and young people should be encouraged to explore such areas. "The future lies in the hands of our youth", Sir Vivian added, "and it is for us to encourage their adventurous curiosity".

But if Sir Vivian's speech steered clear of the more controversial topics of the day, other parts of the BA's programme promise not to do so. Dame Beryl Paston Brown, a former chairman of the Association of Teachers in Colleges and Departments of Education and a former principal of Homerton College, Cambridge, opened the proceedings of section L (Education) with a swingeing attack on Lord James's report on the training of teachers and issued a warning that student unrest will soon hit the colleges of education—traditionally far less militant than universities. Attacking Lord James's report as disingenuous, she warned that the administrative and financial arrangements behind the report's proposals had not been properly thought out. Teachers should be trained with practical teaching experience and the theory of teaching running concurrently, she said. These should not be separated into two separate cycles as Lord James proposed.

The Leicester meeting is the first to abandon the traditional Wednesday to Wednesday timetable, and as a result

the social weekend and the annual Sermon on Science have disappeared; but if the BA is mercifully a little shorter on pomp than usual, it is scarcely lacking in circumstance. Day-long symposia on the biological effects of pollution, energy resources in this century and beyond, and life and leisure in the city now and in the year 2000, all promise to tackle current issues in a style that is new to the BA, and the association is still busy turning itself—a little painfully—into an organization that is more relevant to the needs of science of the 1970s. Constitutional changes, which have been the subject of much soul-searching within the association for years now, were passed *nem. con.* by the general committee on Monday afternoon, even before the inaugural meeting took place. These changes actually provide the BA membership with an electoral voice for the first time in the association's 141 years, and also

go some way to making its governing bodies—general committee and the council—a more manageable size.

And if the constitution has improved, so has the association's financial position. Having made a small profit last year, the future seems much more secure than in recent years now that the Department of Education and Science is to provide £20,000 a year for the next two years through the Royal Society to help the BA continue its work. Replying to Sir Vivian Fuchs's inaugural speech, Sir Alan Hodgkin, President of the Royal Society, said that he feels that the two organizations (the Royal Society and the BA) are complementary and he looks forward to a closer working relationship between them.

The BA also has to gauge reaction to its shorter, more compact, programme—just over 200 lectures this year compared with 300 last year—and to its Monday to Saturday timetable, which

ASTRONOMY

Whose Finger Points

from our Special Correspondent
Sydney, September

THE visit of Mrs Margaret Thatcher, Secretary of State for Education and Science in the British Cabinet, has apparently brought to light a dispute between Britain and Australia on the management of the 150-inch telescope, jointly financed by the two countries and now nearing completion at a site 350 miles north-west of here. From a strictly technical point of view, the construction of the telescope has gone well, although there are some who take the view that it would have been prudent to carry out a more detailed investigation of the seeing at the site before sinking \$A13 million in it. The dispute which has arisen concerns the management of the telescope once it is a going concern. Over the past five years, it has been assumed by astronomers in Britain that the existence of the Anglo-Australian telescope would give them access to an instrument which is potentially important in the exploration of the southern skies, and it has been assumed that one result would be the appointment of a director with responsibility for the management of the telescope, including responsibility for administration, for the conduct of the user committee which, it has been agreed, will allot time on the instrument and for the continuing improvement of

the equipment (which may be quite expensive). A meeting of the six-man board of management of the telescope held towards the end of last year is understood to have confirmed this impression.

The Australian National University at Canberra is, however, far from willing to agree that the Anglo-Australian telescope should have an independent director. The university is already responsible for the management of the Mt Stromlo telescope, which is in many ways regarded as an adjunct of the university's astronomy department. To the extent that the Anglo-Australian telescope will in some respects make the equipment at Mt Stromlo appear less glamorous than it has seemed so far, it is natural that the Australian National University should wish to take the new telescope under its wing. Opposition to this proposal was voiced at a meeting of Australian astronomers held during July, and there is also a chance that the Science Research Council, responsible for the administration of the British share of the cost of the telescope, will support this point of view. The Australian National University has in defence of its view of how the telescope should be managed the cosiness of its relationship with the Canberra government and the complaint that if other potential users of the telescope are now so sure that they know how the telescope should be managed, then surely they would not have left the issue unsettled for so long.

seems to be meeting with cautious approval among the 1,800 or so who have arrived at the meeting so far.

The association has announced that its new secretary and chairman of council is to be Dr Magnus Pyke who is currently a council member and is a former president of section X (General). He will take office in September 1973 after the association's meeting in Canterbury on the retirement of Dr J. A. V. Willis, the current secretary. Dr Pyke will take up the new office assuming the proposed changes in the BA's constitution have been approved by the Privy Council by September 1973.

Meanwhile, apart from the serious scientific lectures there is much to amuse those attending the meeting, with a Science Fair, the excursions and the inevitable section dinners. Leicester—which was last host to the BA in 1933—has risen to the occasion and is displaying the glories of its scientific and technical industries in an exhibition entitled "Expo Leicester 1972" in the city's Abbey Park, beneath a giant tent that looks like a canvas replica of the roof of the Munich Olympic stadium.

CIVIL SERVICE

Pay Research Problems

THE Institution of Professional Civil Servants has failed in its latest attempt to have the pay of scientists within government determined by means other than pay research. Twelve months after Mr William McCall, general secretary of the institution, vowed that there would never be another pay research exercise for government scientists, the joint government and IPCS committee set up to review the criteria for determining salaries has failed to reach an agreement.

Mr McCall writes in the September issue of *State Service* that the gap between the institution and the government cannot be bridged by further negotiation and "we are now at a point where there is once again a real danger of confrontation unless an early solution is found". With memories of the long dispute in the summer of 1971 still clear, the institution is not keen to have another confrontation with the Civil Service Department, and Mr McCall has now proposed that an independent committee be set up to examine the evidence.

The IPCS bases its opposition to pay research on the grounds that the government employs over 17,000 scientists and inevitably, it says, industrial pay scales are either directly or indirectly affected by the government scales. Thus pay research, which should ensure that scientists employed in government laboratories are not underpaid com-

pared with scientists in industry, in this case, according to the IPCS, does not provide a valid comparison.

Both the government and the IPCS agree in the joint report that organizations outside government do take into account the general level of salaries, including those within the scientific Civil Service, when carrying out annual reviews of salaries but this apparently was not enough to convince the CSD that pay research should not be applied to government scientists.

Other interesting findings of the joint investigations include the fact that outside government laboratories, most scientists leave research and development between the ages of 28 and 35. Also, in contrast to the scientific civil service, most companies which were investigated by the joint committee have pay scales which run across the company and are applicable to all duties. One of the recommendations of the Fulton committee was that the Civil Service should also have an all-embracing pay scale but the IPCS has found it difficult so far to persuade the government to institute this below under-secretary level, although there has been agreement in principle that the Science, Administration and Technology categories should have the same pay scale.

The Civil Service Department had not decided at the beginning of this week whether to accede to the IPCS's request for an independent committee to study the evidence. A spokesman for the department said that a decision would be made soon but he also confirmed that the department has no plans to use anything but pay research to determine the salaries of scientists employed by the government.

REACTORS

Collaboration at Grenoble

THE government has decided that Britain should not build its own high flux reactor and that British scientists would be better served by collaborating with the French and West Germans in work with the recently opened reactor at Grenoble. This decision, which is contrary to the proposal of the SRC committee for Neutron Beam Research, has disappointed Professor E. W. J. Mitchell, of the University of Reading, chairman of the SRC committee, who said earlier this week that he thought the wrong decision had been taken. Professor Mitchell added, however, that he was glad that a decision had been made at last and, provided the negotiations with the French and West Germans, which will start soon, were successful, he would do his best to make the arrangement a success.

The Science Research Council, after long deliberations, decided a year ago to ask the government for £22 million

over an eight year period to build a high flux beam reactor in Britain. This decision was taken instead of the alternative of joining with the French and West Germans as equal partners in the Grenoble reactor project.

Professor Mitchell pointed out that if the government had decided to build a reactor in Britain then until it became operational an *ad hoc* arrangement would have been made so that British physicists, chemists and biologists could make use of the facilities at Grenoble. In fact there are British scientists working at Grenoble already even though the reactor is as yet not fully in use.

One of the factors that made the government reject the recommendation of the SRC was undoubtedly the cost. It is estimated that an agreement with the French and West Germans would cost £11 million—one half of the cost of building a new reactor—but Professor Mitchell points out that for this money British scientists will only be getting a third of the experimental time they would have got if they had their own reactor.

One of the consequences of the decision to enter into negotiations with the French and West Germans is that the United Kingdom Atomic Energy Authority will not acquire any extra irradiation facilities, the need for which was one of the arguments which swayed the SRC Neutron Beam Committee towards recommending that a high flux beam reactor be built in Britain. One fifth of the total estimated cost of the British reactor of £22 million was to be paid by the UKAEA in return for one fifth of the experimental time.

The UKAEA, however, denies that it has had a change of mind during the past year about its irradiation requirements. A spokesman said earlier this week that the possibility of the UKAEA using the Grenoble facilities was not remote and it was possible that the authority would enter into negotiations to obtain experimental time if a successful agreement about collaboration was reached by all parties concerned.

This decision does not rule out the possibility of Britain, either alone or in collaboration with some other European countries, constructing a reactor at a later date, according to a government spokesman. Professor Mitchell, however, thinks that this is unlikely during the next few years.

An interesting facet of the present debate is the much lower estimated cost of the British reactor compared with the Grenoble reactor, which has cost about £33 million. Professor Mitchell said that the lower cost would be achieved by economies on the engineering side.

One of the people left out on a limb by the present decision is Dr L. W. C. Hobbs, of the Neutron Beam Research

Unit at the Rutherford Laboratory. This unit was set up in 1971, no doubt on the strength of the decision to ask the government to provide finance for the British high flux beam reactor and since then the unit has been involved in preliminary work on reactor development. Dr Hobbs said on Tuesday that there was no question of his unit, which has a complement of 28 people, being declared redundant but the direction of their work must change. There is a need in Britain, Dr Hobbs said, for such a unit to provide back-up support for neutron beam research and from now on their work would be oriented towards collaboration with Grenoble.

RADIO ASTRONOMY

West Ford Replayed

by our Astronomy Correspondent

THERE is widespread apprehension in radio astronomy observatories that the launch of a NASA satellite next year may threaten radio observations of the universe. The satellite is the sixth in the series of Applications Technology Satellites (ATS) and is intended as a preliminary to the development of satellites which will broadcast television programmes direct to domestic receivers on the ground.

In spite of this laudable aim—which among other things could lead to the development of an educational broadcasting system for the developing countries—many radio astronomers are regarding the launch of ATS-F with almost the same distaste as they regarded the West Ford project a few years ago. Radio astronomy was then threatened with the possibility of the indiscriminate scattering of metallic needles in Earth orbit. Now radio astronomers fear that the broadcast signal from ATS-F will spill over into one of the bands of the radio spectrum reserved exclusively for radio astronomy. The problem is made more acute because, as one radio astronomer has pointed out, radio observatories can be sited away from the interference produced by large towns and road and rail traffic, but there is no hiding from a geostationary satellite.

Radio astronomers are also concerned over the ATS-F affair because of what some of them regard as a cavalier treatment of the international regulations which govern the allocation of frequencies in the radio spectrum. The radio astronomy band now in danger extends from 2,690 MHz to 2,700 MHz, but the International Radio Regulations also ask other users to bear in mind that astronomical observations also extend from 2,690 MHz down to 2,670 MHz. Broadcasting satellites have been allocated the band from 2,500 MHz to 2,690 MHz, so on

paper at least there should be no clash so far as the exclusive radio astronomy band is concerned, but radio astronomers point out that the real picture is more complicated because the broadcasting signal will spill into the radio astronomy band.

The details were spelled out in a report in 1971 to the International Telecommunications Union by its advisory body, the Consultative Committee on International Radio (CCIR). The CCIR report shows that radio observatories require an interfering signal within the 2,690–2,700 MHz band to be less than $-247 \text{ dBW m}^{-2} \text{ Hz}^{-1}$ for a source anywhere in the sky, and very much less if it happens to be close to the astronomical object under observation. But the first proposal to use the broadcasting satellite service would provide

a signal spilling into this band at a level of $-232 \text{ dBW m}^{-2} \text{ Hz}^{-1}$, which is more than thirty times the maximum level even under the restricted circumstances that radio astronomers would abandon the part of the sky where the broadcasting satellite is placed.

Both the radio astronomy band and the broadcasting satellite band are, however, equally recognized by the ITU regulations. It seems that most radio astronomers became fully aware of the present threat as recently as last month's meeting of the General Assembly of the Union of International Scientific Radio in Warsaw, when they were told of next year's test of the satellite broadcasting system by ATS-F which will operate at 2,670 MHz. It is expected that European observatories will be below the satellite's horizon, but all

Fischer Acclaimed as Champion

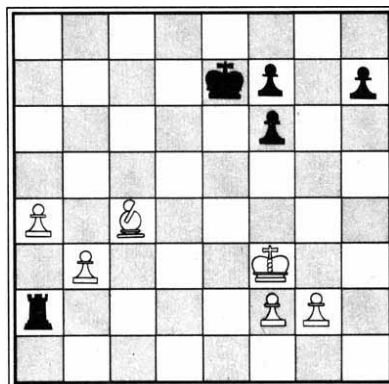
By means of a draw in the 20th game and a win against Spassky in the 21st game, Fischer has reached the coveted total of $12\frac{1}{2}$ points and consequently becomes the new Chess Champion of the World. The 20th game was fairly quiet since Fischer seemed to be adopting the policy of playing carefully during the latter part of the match, even when playing white. Spassky made some effort to win the end game of rook and two minor pieces each, but the position was always too level for him to make much impression.

The 21st game found Spassky (white in a Sicilian Defence) handling the opening rather listlessly, and it was not long before Fischer gained a slight initiative. Spassky tried to hold on by sacrificing the exchange for two connected passed pawns on the queen's side and the game seemed to be heading for the eighth successive draw of the match when in the diagrammed

position he erred by playing in move 30, P-KN4. This allowed a neat reply by Fischer that established a passed king's rook's pawn for him. Spassky's sealed move (41, B-Q7) was a further mistake that allowed this pawn a free passage up to the sixth rank rendering any further resistance hopeless, but Spassky obviously realized that even a draw with white was simply not good enough to pull the match out of the fire.

By winning 7 and losing only 2 games played, Fischer has clearly shown his superiority in this match over Spassky. At 29 Fischer has probably reached the peak of his chess-playing ability, combining maximal physical stamina with a single-minded development of his considerable mental prowess for the game. In comparison with previous World Champions he seems to unite the imaginative boldness of Alekhine, the technical mastery of Capablanca and the fighting spirit of Lasker. It is not yet clear that he is quite as deep a strategist as Botvinnik at his best. Nevertheless, he is certainly a very worthy champion and his fluid and attractive style of play seems to have done much to help popularize the game of chess.—J. P.

WHITE
SPASSKY



FISCHER
BLACK

The position after black's 29th move in the 21st (and last) match game.

White: Spassky, Sicilian Defence,		Black: Fischer The 21st Game	
White	Black		
1 P-K4	P-QB4	22 BxP	RxR
2 N-KB3	P-K3	23 BxRP	R-Q7
3 P-Q4	PxP	24 R-K2	RxQBP
4 NxP	P-QR3	25 BxR	RxR
5 N-QB3	N-QB3	26 P-R4	R-Q1
6 B-K3	N-B3	27 B-B4	R-Q7
7 B-Q3	P-Q4	28 K-N3	R-R7
8 PxP	PxP	29 K-B3	K-B1
9 O-O	B-Q3	30 P-KN4	K-K2
10 NxN	PxN	31 PxP	P-B4
11 B-Q4	O-O	32 B-N8	P-B3
12 Q-B3	B-K3	33 K-N3	P-R3
13 KR-K1	P-B4	34 K-B3	K-Q3
14 BxN	QxB	35 K-N2	R-R8
15 QxQ	PxQ	36 B-K6	K-K4
16 QR-Q1	KR-Q1	37 B-Q7	K-B5
17 B-K2	QR-N1	38 B-K6	R-QN8
18 P-QN3	P-B5	39 B-B4	R-N7
19 NxP	BxN	40 B-K6	R-R7
20 RxB	BxP ch	41 B-Q7	P-R4
21 KxB			

White resigned

radio observatories in the United States and Canada will be affected.

One radio astronomer who is deeply involved in the protection of the radio astronomy bands says that the International Radio Regulations seem to offer no power to radio astronomers to prevent damage to the exclusive band, and describes the affair of ATS-F as "a sad and ironic example of the rapidly growing misuses of the electromagnetic spectrum".

JAPAN

China Comes Closer

from our Special Correspondent,
Tokyo, August

THE prospect of a *rapprochement* with China has excited not merely the politicians and their protégés, the chairmen of the large industrial companies, but also the scientific community, which would welcome closer links with Chinese universities and which acknowledges that the development of a stronger trading relationship with mainland China could profoundly influence the development of Japanese science in the coming decade. Since the appointment of Mr Tanaka's government last June, the talk of the development of the technology of anti-pollution has been more clamant than ever, but the prospect that Japan may now become the source of all kinds of new technologies for mainland China—consumer goods are likely to be much less saleable than machinery—may yet revive some of the old excitement about technology.

This prospect no doubt explains why so much attention is being given to the preparations for Mr Tanaka's visit to Peking in the next few weeks, and in particular to the agreement that a portable ground station for satellite telecommunications should be installed by Kokusai Denshin Denwa Company. The company, which has a monopoly on external radio and cable services, has already arranged to increase the number of short-wave radio telephone circuits between Tokyo and Peking from four to six, and there is also talk that the Japanese National Railways would be prepared to provide the Chinese with the technology of the high speed railway link now working between Tokyo and Osaka so long as the Chinese were prepared to buy rolling stock or to pay for the installation of new lines. In short, the prospect of a changing relationship with China is appealing because it may make demands on branches of technology which have not so far been directly involved in the export business.

In spite of appearances to the contrary, there is also some quiet pleasure at the agreement between Prime Minister Tanaka and President Nixon

that \$320 million would be spent on advanced purchasing of enriched uranium from the United States. The immediate objective, of course, is to make the Japanese dollar surplus seem less horrendous to the United States, but it is also acknowledged that by the 1980s, it will be hard to secure fuel supplies for the 60,000 MW nuclear reactor capacity expected to be operating by the middle of the decade. The new agreement will give the Bureau of Atomic Energy a lien on 10,000 units of separative work at American enrichment plants at a time when these will be most necessary.

Japanese willingness to rely on American facilities has also been apparent, in the past few days, in a strange dispute between the National Broadcasting Corporation (NHK) and the National Telecommunications Organization (NTT) on the one hand and the Space Development Agency on the other. The two former organizations have long been critical of the plan to develop an independent launching capability for telecommunications satellites and were instrumental in persuading the Space Development Commission that the three-stage rocket needed to launch synchronous communications satellites should be built on the Thor-Delta rocket well tested in the United States and now being manufactured by the Space Development Agency under licence. But the telecommunications authorities are still impatient with a plan which cannot, at best, launch independent telecommunications satellites before 1979 and have therefore let it be known that they would like to see four Japanese-built satellites launched with American rockets in 1975 and 1976. NHK's proposal would involve direct reception of television signals broadcast by satellites.

The two public corporations have had their knuckles rapped by Mr Makoto Miike, Minister of Posts and Telecommunications, who says the proposals are directly in conflict with the strategy that led to the creation of the National Space Development Agency three years ago. At the agency, it is said that the director first heard of the specific plans now canvassed by NHK and NTT by reading the newspapers and that he has not even now been given full details. The fact that the row has come out into the open in this way can no doubt be taken as a sign that there is more trouble ahead.

The campaign against pollution is being waged on every front. In the past few days, perhaps the most surprising development has been that the Ministry of International Trade and Industry has laid down a standard for the allowable concentration of sulphur dioxide in atmospheric gases of 0.15 parts per million, compared with a concentration of 0.05 ppm provided for in

current legislation. The ministry says quite openly that its new standard will only be attainable if there are radical changes in industrial methods and, fair play, it is already spending large sums of money on applied research aimed at devices for controlling environmental pollution. And in the past few weeks, persistent eaters of tuna fish have been warned of mercury contamination—one worker at the Central Wholesale Market has been found to have 25.62 ppm of mercury in a sample of hair. On the basis of a government survey, it has also turned out that the degree of contamination, unchecked until three or four years ago, is worse than anybody expected.

SOVIET SCIENCE

Soviet Education Policy

from our Soviet Correspondent

A HEAVY emphasis upon the sciences is a principal feature of Soviet education policy, and expansion in the field of higher education implies an expansion of science faculties and institutes. The new party and government resolution on "Measures for the Further Improvement of Higher Education" suggests, however, that this expansion is not sufficient to keep pace with the growth of the Soviet economy.

In many cases the level of theoretical and professional knowledge of the graduates "does not correspond to the increased requirements of science and industry". There are delays in the introduction of modern methods, and recent discoveries and innovations are not dealt with in the syllabus.

The close connexions advocated by educational policy between institutes of higher education and industry or agriculture are in many cases "still weak", and insufficient attention is paid, in teaching and research, to "the immediate problems of science and technology". In some areas there have been failures in providing proper finance, so that laboratories are poorly equipped. Finally, the planning for the training, distribution and use of specialists is said to be "not in complete correspondence with the needs of the national economy".

The resolution calls for the cooperation of All-Union and regional bodies concerned, from the Academy of Sciences downwards, to deal with the problem. Syllabuses are to be revised and new textbooks prepared with greater emphasis on the "general science and general technology disciplines". The teaching of "the organization of labour and control", engineering psychology, industrial aesthetics and computer technology is especially earmarked for improvement.

NEW WORLD

Skeletons in the Nuclear Cupboard

by our Washington Correspondent

THE General Accounting Office (GAO), which recently embarrassed the Republican Party by disclosing alleged violations of the law in connexion with campaign funding, has now also embarrassed the Atomic Energy Commission by publishing a critical report on the AEC's regulation of users of radioactive materials. Not only does the report document a number of alarming cases of public exposure to overdoses of radioactivity, but it also casts doubt on the commission's ability to prevent blatant violation of its own regulations. On the bright side, however, the report does suggest that the commission is beginning to take steps to put its house in order.

The GAO investigation was concerned with regulation of licences for use of radioactive compounds ranging from fuel processing and waste disposal to research and medical treatment. Some 16,300 such licences had been issued by the AEC up to June last year, and of these 8,200 were being regulated directly by the AEC, while the remaining 8,100 were regulated by the states under agreement with the AEC.

The regulations are supposedly designed to ensure that public exposure to radiation is kept within safe limits, whatever they are, but the GAO has found that this intention is not always fulfilled. The report says that in 5,616 inspections carried out by AEC staff between January 1968 and December 1971, there were no fewer than 1,932 violations of the regulations—ranging from insufficient warning of radioactivity areas and poor record keeping to blatant failure to report accidents and totally inadequate safety precautions. Although most of these violations were minor and, according to the GAO, were put right after a letter or an informal warning from the AEC, some were particularly serious and were not put right for a long time if at all. (The GAO euphemistically refers to such violators as "problem licensees".) Perhaps the most serious allegation in the GAO report is that the AEC took no stronger action against the majority of the problem licensees than to ask for an explanation of the violation and details of the steps the violator intends to take to prevent future violations. Moreover the GAO takes the AEC to task for not moving quickly enough after a violation had been discovered.

The GAO inspected ten problem

licensees in detail and a short description of some of the violations is sufficient to show the seriousness of them. In one case, for example, a fuel processing company was inspected by the AEC 23 times up to August last year, and 18 of the inspections turned up one or more violations of the regulations. Nine inspections found radiation levels above the limits in and around the plant, including in an occupied apartment block next door, and there was also a history of overexposure of employees to radiation. But not until March 1971 did the AEC threaten the licensee with non-renewal of his licence, after which, the GAO reports, steps were taken to correct the violations.

In another plant, excess radiation levels were found in a business firm next door and radioactive contamination was even found on public sidewalks around the plant. Eventually the licence was modified to include stronger controls, after which the plant suspended operations for some time. But soon after it started up again, there was an accident which resulted in plutonium contamination of several areas of the plant, two of its employees and the surrounding area; the AEC was then forced to deny the licensee's request for renewal of his licence. The GAO also examined two cases involving medical facilities in which patients were given millicurie doses of radioactive compounds instead of microcurie doses, chiefly because of inadequate training and supervision of staff. Both resulted in the death of the patient. The AEC inspected one of these two medical facilities in April this year, and found six items of noncompliance with the regulations, but took no enforcement action.

Some of the reasons the GAO cites for the AEC's poor record in enforcing its regulations are common enough—for example, there is a lack of staff, with only 31 inspectors and investigators to police some 8,200 licensees. But the accounting office also believes that the AEC's procedures are also partly to blame. For one thing, until September 1971, the agency lacked enforcement powers stronger than simply asking for explanations of violations but short of suspending or not renewing licences. Consequently, since licences were rarely revoked, the AEC did not have sufficient weapons at its disposal to force licensees to comply with the regulations. (Why the AEC did not simply shut down plants until they complied with the regu-

lations is, however, open to question.) The agency can now impose civil penalties on violators, however.

The GAO also criticizes the AEC for not requiring licensees to give proper training and supervision in the administration of radioactive materials in medicine, but the agency is now taking steps to remedy this situation.

In defence of the AEC's enforcement record, however, L. Manning Muntzing, the Director of Regulation, pointed out in a letter to the GAO in March this year that the majority of the violations were cleared up after a letter from the AEC, and that the number of problem licensees is very small—the agency identified nineteen such cases between May and July last year. Nevertheless, he said that the AEC intends to use its new power to impose civil penalties to good effect. Muntzing also points out that the radiation levels set by the AEC are "much lower than levels which are likely to cause observable biological damage" and that "exposures in excess of the regulatory limits discussed in (the GAO report) should not be viewed as necessarily affecting the health of the exposed individual". Finally, Muntzing suggests that since there have only been twelve known cases of misadministration of radiopharmaceuticals, in spite of the fact that some eight million such administrations are performed each year, the safety record, compared with that for non-radiological drugs, "appears to be extremely favourable".

Nevertheless, the fact remains that one third of the AEC's inspections have turned up violations of regulations designed to protect public health. Unless the AEC acts promptly and decisively to remedy such violations, public confidence in the commission will be even further eroded.

NITRITES

Nitrites in Trouble

by our Washington Correspondent

THE American public each year consumes some 1,060 million pounds of food additives—about 5 pounds per person. Not surprisingly, there is growing public concern about the effects of these additives, and consumer groups have recently won a series of spectacular victories over the food manufacturing industry, not least of which was the ban on cyclamates in 1969 and the recent execution order on diethylstilboestrol. The Food and Drug

Administration, which has the task of regulating the almost 3,000 food additives now licensed for use in the USA, is increasingly being caught in the uncomfortable crossfire between consumer groups and the powerful food industry. The latest, and perhaps the greatest, of its headaches is the mounting concern over the safety of sodium nitrite, an additive which has been used for centuries in the curing of meats.

Last month, the Intergovernmental Relations Subcommittee of the House Government Operations Committee issued a report which is strongly critical of the FDA's policies towards nitrite, and lawyers connected with Ralph Nader's Center for the Study of Responsive Law have gone to court to force more stringent regulation of the additive. The issue is complicated by the fact that nitrite has several uses, including the entirely cosmetic purpose of making cured meat look red and the possibility that it may prevent the growth of *Clostridium botulinum*, and therefore afford protection from deadly botulism.

Sodium and potassium nitrates have been used in curing meats at least since Roman times, chiefly to fix the red colour of the meat to make it look more appetizing. But in the 1920s it was discovered that the colour fixing property is actually caused by nitrites formed by bacterial decomposition of the nitrates and in 1925 the US Department of Agriculture gave formal approval for the use of nitrites in curing meat. It is now usually used in conjunction with nitrates, and the maximum level of nitrite that is allowed in the cured product is 200 parts per million.

Concern about the safety of nitrites once centred around its acute toxicity—it can combine with haemoglobin to form methaemoglobin which reduces the blood's capacity to transport oxygen. Some deaths have in fact occurred when children have eaten food heavily contaminated with nitrites, mostly formed from bacterial decomposition of naturally occurring nitrates. But concern has recently shifted to the possibility that nitrites may combine in the stomach with amines and amides to form highly carcinogenic nitrosamines, a suggestion which is being hotly debated, and which throws up the question of whether nitrites are covered by the Delaney amendment.

The suggestion that nitrosamines may be formed in the human stomach was first raised in the late 1960s, and in the past few years there have been numerous studies which have produced nitrosamines in the stomachs of animals fed mixtures of secondary amines and nitrites. Asked last week whether he believes that the possibility of nitrosamine formation in the human stomach has been firmly established, Dr William

Lijinsky of Oak Ridge National Laboratory, who has done much of the pioneering work in the field, said, "In my mind there is no doubt". He pointed out that the reaction between nitrite and amines takes place readily in test tubes in the presence of dilute acid, which is just the condition that exists in the stomach.

The Food and Drug Administration disagrees, however. In a statement sent around the FDA immediately after the publication of the report of the Intergovernmental Relations Sub-committee, it was suggested that "we do not know whether the low levels of nitrates and nitrites now permitted by regulations actually combine with amines in the stomach to form nitrosamines". In any case, a spokesman for the Food and Drug Administration pointed out last week that secondary and tertiary amines are relatively uncommon in nature. They are, however, widely used in many drugs, including the antibiotic oxytetracycline, tolazamide, a drug taken by diabetics to reduce blood sugar, and disulfuram, a drug used to control alcoholism.

Perhaps the most important evidence about the danger of nitrosation occurring in the stomach has come from animal feeding studies in which rats have been fed mixtures of nitrites and amine drugs. A study carried out at the Eppley Research Institute of the University of Nebraska produced tumours in Swiss mice, and studies now being performed by Dr Lijinsky are showing a high incidence of malignant tumours in mice fed mixtures of amines and nitrites. The complete results of Dr Lijinsky's studies have not yet been published, however.

The controversy surrounding the possibility that nitrites may lead to the formation of carcinogenic nitrosamines is more than matched by controversy surrounding the reasons for using the additive. Although there is no question that nitrites impart characteristic flavour, colour and texture to cured meats such as bacon, ham and sausages, it is being defended by the food industry and also by the Department of Agriculture and the Food and Drug Administration because it prevents the growth of *Clostridium botulinum*.

Even those who are most critical of the FDA's regulatory policies for nitrites accept the possibility that it is valuable in preventing botulism from some products, and they are not asking for its immediate withdrawal. The law suit filed by Nader's centre, for example, asks simply for more stringent regulations, and Harrison Welford, a lawyer concerned with the suit, said last week that "nitrite clearly does have some use in meats to prevent botulism". What is at issue, however, is, first, whether nitrite is needed to control growth of *Clostridium botulinum* in all

the products for which it is used, and second, whether the regulations now in force are sufficient to protect against botulism.

For one thing, nitrites are used in curing bacon, although bacon is always cooked at temperatures which would destroy the spores and the botulism toxin. For another, there is considerable doubt about the viability of some cured meats as a culture medium for the spores—between 1950 and 1963, for example, meat was involved in only one case of botulism poisoning, and that was caused by contaminated liver paste.

But the chief item that has been seized upon by the FDA's critics is an apparent contradiction in the regulations for preventing botulism, and also the suggestion that the 200 ppm limit established for the additive has no scientific basis. The Intergovernmental Relations Sub-committee claims, for example, that the 200 ppm limit was set in 1925 on the basis of the levels of nitrite found in meat cured with nitrites, this level became the tolerance level in 1925, and it has continued ever since, without any scientific justification.

In the 1960s, however, the Food and Drug Administration allowed the use of nitrates as a preservative in smoked chub fish, to prevent the growth of *Clostridium botulinum*. The regulations require that a minimum level of 100 ppm should be present in the fish for the required protection, and an upper level of 200 ppm was set. No lower limit has ever been set for meats, however, and so the committee argues that if a level of 100 ppm is required for fish, why is no lower limit required for meats? The lawsuit filed by Nader's centre is also based upon this apparent contradiction, for the contention is that the US Department of Agriculture licensed use of nitrites in the 1920s as a curing agent, not as a preservative. The lawsuit therefore contends that the additive is not exempted from the Food and Drug Act, as are other additives approved before the act came into force, because it is being used in a manner which has never been approved.

Underlying the whole controversy about whether or not nitrite regulations should be made more stringent is the question of the FDA's attitude to potential, but speculative, risks to health. What the agency is in effect saying is that until the risk of health hazards from nitrites can be proved, use of the additive should be continued unchanged. The agency's critics argue, however, that if there is a risk of cancer, the use of the additive should be strictly regulated until there is proof that no risk exists. In the ten months starting in June last year, the agency examined only eight fish samples for the level of nitrites.

NEWS AND VIEWS

Measuring Optical Frequencies and the Speed of Light

DURING the decade in which lasers have become prominent in physics, an orange line from a krypton-86 discharge lamp has been used as a standard for wavelength comparison. The accuracy of 1 in 10^8 with which the defined wavelength is reproduced is, however, far inferior to the precision with which lasers, with their much narrower spectrum and greater coherence length, may be compared. More recently lasers have been locked on to saturated molecular absorptions, thus providing optical frequency standards with reproducibilities of 1 in 10^{11} at $3.39\text{ }\mu\text{m}$ (*Phys. Rev. Lett.*, **22**, 4; 1969), and about 1 in 10^{10} at 633 nm in the visible (*Appl. Phys. Lett.*, **14**, 362; 1969) and for any of the several hundred CO_2 laser transitions between 9 and $11\text{ }\mu\text{m}$ (*Appl. Phys. Lett.*, **17**, 53; 1970). These stabilized sources have stabilities approaching that of the present standard of frequency—a caesium transition near 9 GHz which is accurate to 1 in 10^{12} . There is a great incentive therefore to measure in some way the frequencies of the optical “standards” in terms of the caesium standard. Measurement of the wavelength by comparison with the output of the krypton lamp would then provide a value for the speed of light *in vacuo* that is limited entirely by the lamp itself. As the krypton lamp is properly a quantum frequency source and as observations of pulsar radiation show that dispersion in interstellar space over a spectral range from the microwave to the ultraviolet is at a level $\lesssim 10^{-20}$ (*Phys. Rev. D*, **5**, 796; 1972), it is possible to contemplate an agreed value of the speed of light as a means of deriving length, as well as the time scale, from the quantum frequency standard.

Experiments to measure the speed of light to the full accuracy of the krypton lamp are in progress or planned at several standards laboratories. They are made possible by recently discovered laser mixing devices. The metal-to-metal point contact diode first reported by Javan's group at MIT (*Appl. Phys. Lett.*, **12**, 401; 1968) has been used to extend measurement to the $3.39\text{ }\mu\text{m}$ methane stabilized laser at 88 THz using HCN, H_2O and CO_2 lasers as transfer oscillators (Evenson, K. M., *et al.*, *Appl. Phys. Lett.*, **20**, 133; 1972). Measurement of the lower laser frequencies can be simplified by using a point contact Josephson junction at liquid helium temperatures: McDonald *et al.* have observed mixing of the 400th harmonic of a 9 GHz source with a 3.8 THz laser signal (*Appl. Phys. Lett.*, **20**, 296; 1972).

Evenson and his associates at the US National Bureau of Standards, Boulder, have already announced at the International Quantum Electronics Conference held in Montreal in May and at the Conference on Precision Electromagnetic Measurements at Boulder in June a preliminary value of the speed of light to 2 in 10^8 from measurements on the 88 THz stabilized laser. An experiment involving the measurement of a CO_2 laser frequency and aimed at achieving similar accuracy is in progress at the National Physical Laboratory, Teddington (*Phys. Bull.*, **23**, 15; 1972).

The measurement of the frequency of a visible Lamb-dip stabilized HeNe laser and consequent determination of the speed of light to be $299,792.462 \pm 0.018\text{ km s}^{-1}$ (a

standard deviation of 6 parts in 10^8) by Z. Bay, G. G. Luther and J. A. White at the National Bureau of Standards, Washington, DC (*Phys. Rev. Lett.*, **29**, 189; 1972) differs from the above in its use of an interferometric technique to compare waves of visible and microwave frequencies. Their accuracy for the speed of light is a factor of five better than the value accepted at present, which is the same as that obtained by Froome in 1958 using a 72 GHz microwave interferometer. Problems from diffraction in measuring the microwave wavelength are avoided by Bay *et al.*, essentially through using the microwave frequency to modulate a visible “carrier” wave. Although the accuracy falls short of that of the krypton lamp, their result is valuable for its independence of method from those being obtained using frequency multiplication. Happily, the progressively more accurate results of Froome, Bay *et al.* and Evenson *et al.* are in agreement.

Bay *et al.* have amplitude modulated the visible laser signal at 10 GHz using an electro-optic crystal. Sum and difference frequency sidebands are produced on the visible “carrier” which is filtered out before passing the sidebands through the cavity of an evacuated Fabry-Perot interferometer. The two sidebands are phase sensitively detected after separation with optical filters, and a reference modulation is applied to the length of the cavity. A servo locks the Fabry-Perot cavity to the laser frequency by equalizing the transmission of the sidebands, while a second servo controls the 10 GHz modulating frequency with reference to the cavity by maximizing the transmission of the sidebands. At first sight the second servo signal, being derived from a difference of orders about 10^4 smaller than the visible order of interference, would seem to offer much less precision than the servo which controls the Fabry-Perot cavity to the laser. It turned out, however, that the servo signal is the difference of the phase sensitively detected sideband signals so that strongly correlated noise from short-term fluctuations in the laser frequency, the air path, optics and cavity length are cancelled. Uncorrelated noise such as shot noise in the photodetectors becomes a limitation. Bay and his associates averaged the microwave frequency counting for 100 s to reduce the fluctuations to a few parts in 10^8 .

Larger excursions in the frequency count (a few parts in 10^7) occurred over periods of 10 to 20 min but were random and were attributed by the experimenters to optical feedback from the Fabry-Perot cavity to the laser. This feedback can be reduced by an improved isolator but is still an important difficulty.

Corrections for systematic error are necessary in the experiment. The effect of phase shift at the cavity mirrors was cancelled by making measurements of the locked microwave frequency for different cavity lengths, near 12 cm and 25 cm respectively. This left residual errors of less than 10^{-9} from mirror imperfections in the presence of different beam diameters for the two sidebands. Calculation of the diffraction phase shift from cavity theory left a similar residual uncertainty.

By comparison, the frequency multiplication methods for measuring optical frequencies are free from the

problems of diffraction and geometrical accuracy and stability which beset interferometry. The potential accuracy is therefore greater, but the apparatus at present is much larger and more complicated than that of Bay *et al.*, and not yet able to reach visible frequencies.—D. K.

SUPERNOVAE

Insight into Type I

by our Cosmology Correspondent

ALTHOUGH the spectra of type II supernovae are not too dissimilar to those of novae—more common but less violent eruptions of normal stars—and have thus been open to at least a degree of interpretation, type I supernovae have until recently proved a much tougher nut to crack. Now, a combination of theoretical and observational studies carried out by Charlotte Gordon, of Yeshiva University, New York, is at last yielding results which seem to be laying the empirical base for a better understanding of these objects (*Astron. Astrophys.*, **20**, 79 and 87; 1972).

The principal reason for the differences between the two types of supernovae is that type I occur among population II stars, and type II among population I—an unfortunate choice of nomenclature left over from an earlier age of astronomy—and that population II stars are deficient in heavy elements. Population II stars form the halo population of our own Galaxy, and predominate in elliptical galaxies, whereas population I stars, generally regarded as “second generation” products produced from matter already processed through a nuclear burning cycle (perhaps in population II stars which have exploded), occur chiefly in the spiral arms of galaxies.

It is not surprising, therefore, that population II stars, on the rare occasions that they explode into supernovae, produce supernovae with spectral features quite different with those of type II supernovae. Generally, spectra of type I supernovae consist of wide emission bands, and it is only in the past few years that any of the features have been identified with known lines of oxygen (O I) and helium (He II and He I). The problem is complicated both by the need to study supernovae in galaxies other than our own—for they are far too rare for astronomers using telescopes yet to have caught a glimpse of a “native” supernova—and by the complex and rapidly varying Doppler effects on the spectral features produced by the explosive expansion of a turbulent gas cloud. Gordon has studied the physical conditions in such an expanding shell and

the formation of emission and absorption lines under those conditions. Density, temperature, chemical composition and other effects must all be included in these theoretical calculations before the models can be compared with observed spectra and adjusted until some sort of agreement is reached.

Much of the dynamics in Gordon's models comes from the work of Colgate and his colleagues (*Astrophys. J.*, **157**, 623; 1969; and **143**, 626; 1966). With a dispersion of velocities of up to 2×10^9 cm s⁻¹ within the shell, it is no wonder that the spectra seen are complicated. The chemistry of the shell also poses problems. Hydrogen lines are conspicuous by their absence from these spectra, whereas usually they are the one feature which can be found in spectra of any astronomical object, and Gordon's models suggest that helium is the chief component of the shell, with its ions outnumbering those of hydrogen by ten to one. A further complication is provided by the possible existence of a young neutron star remnant at the supernova site, emitting hard radiation which will be stopped by the expanding shell.

In spite of these difficulties, Gordon has now tentatively identified many lines of helium, oxygen, carbon, iron, and other metals in three supernova spectra—those of the events that took place in 1937 in IC 4128 and NGC 1003, and that of the event of 1960 in NGC 4496. The rapid evolution of the spectra points to a rapid decrease in

the degree of ionization in the inner layers of the expanding supernova shell; after 30 day, Gordon predicts a number density of free electrons of 3×10^{10} cm⁻³, which falls to 10^9 cm⁻³ after 89 day and to 3.5×10^7 cm⁻³ after 285 day. For the 1960 supernova in NGC 4496, Gordon finds that the degree of ionization and effective temperature in the shell required to explain her identifications of the lines point to two possible models. In the first, ionization occurs by the absorption of bremsstrahlung and ultraviolet lines formed in the inner layers of the shell; in the second, ionization is powered by the synchrotron radiation from the newly formed neutron star.

There seems to be no continuum in the spectrum of the NGC 4496 supernova, which consists of a system of emission lines truncated by an overlaying absorption, according to Gordon, and these features can be explained if the outward moving shell is ionized by an intense flux of X-rays.

The first model corresponds to the production of these X-rays in the innermost layer of the shell, which is heated by fast particles from the underlying neutron star, and the second model corresponds to the direct generation of X-rays by the neutron star.

These empirical results are far from complete, and leave many questions unanswered. But they provide a reasonable picture of the sequence of events in type I supernovae which agrees with generally held views about such objects.

Magnetic Field Structure of 3C 273A

MANY broad issues have yet to be resolved before the nature of the extragalactic radio sources associated with radio galaxies and quasars can be fully understood. One problem is how the radio sources are confined so that they do not expand adiabatically and quickly fade, and another is how a supply of energy from the optical object can be so directed to reach the radio component. In the past few years several containment models have been suggested, chiefly using the ram pressure of the intergalactic medium to confine the radio sources. A common feature of these models has been a hairpin magnetic field structure in which the magnetic field lines loop from the optical object to the radio component and back. In the next issue of *Nature Physical Science* (September 11) R. G. Conway and D. Stannard have found, in 3C 273, the first observational evidence of such a magnetic field structure.

The radio source 3C 273 is a quasar with an optical jet. Its radio structure comprises a very compact component, 3C 273B, coincident with the optical

position of the quasar, and a second component, shaped like a cigar, 3C 273A, which is 20 arc s away and lies along a continuation of the jet. Using measurements made with an interferometer at 11 cm at the National Radio Astronomy Observatory, Greenbank, and at 73 cm at Jodrell Bank, Conway and Stannard have been able to find the one-dimensional distributions of total flux, linear polarization and position angle across the source. They find that the magnetic field at the end of 3C 273A nearest to the quasar is parallel to the direction of the jet, while the field at the other end of this radio jet is perpendicular to the jet. In short they have found the first example of the hairpin magnetic field structure predicted by the containment models.

So at last measurements have revealed a magnetic field structure that is in agreement with the theories. It has, however, not been found where it might have been expected, namely in a large powerful radio source such as Cygnus A, but in quite a small source that is only 2×10 arc s.

PROTEINS

Going Native

from our Molecular Biology Correspondent

IF one were to judge from the results of equilibrium experiments alone, one would conclude that the denaturation and refolding of at least the smaller proteins generally involves only two states, with no intermediates of appreciable weight. Ultimately this first approximation to the truth, useful as it has been, is altogether too primitive, for perhaps the most absorbing problem in protein chemistry just now is the resolution of the events that constitute the folding pathway.

A notion which has had wide currency for some time is that the rate-limiting step in the folding process is the formation of structural nuclei (the nature of which has also been the subject of much discussion), which then direct the ensuing structural condensation, according to a series of rapid reactions. Such a scheme has several attractive features, and explains in particular the strong cooperativity which is universally observed in denaturation-renaturation equilibria, as well as the conspicuously small entropy of activation for folding, which could not be easily reconciled with a rate-limiting step involving extensive conformational immobilization. Among the difficulties that arise in the interpretation of kinetics of denaturation is that of deciding whether the pathways are in all cases unique, or whether parallel processes occur, and also whether slow steps might arise from dead-end pathways which lead to incorrect conformational states, and which have to be retraced to permit a new start. Criteria for discriminating between such possibilities were not long ago formulated by Ikai and Tanford. The most profound investigation of the kinetics of the folding process has come from Baldwin's laboratory, and, with ribonuclease as a model, has for the first time penetrated to this level of complexity, and demonstrated the existence of a slow nucleation reaction.

In following the kinetics of conformational processes, it is necessary to make use of some kind of spectroscopic manifestation, which will in general contain contributions from several structural elements. Thus it is difficult to be sure that the separable steps in the kinetics of ribonuclease denaturation, followed in terms of the development of the aromatic difference spectrum, do not arise from differences between the rates of exposure of the various residues. With this in view, Tsong and Baldwin (*J. Mol. Biol.*, **69**, 149; 1972) have examined the kinetics using a dinitrophenyl derivative of ribonuclease. The substituent is on

Lys-41, which is one of the two lysines on either side of the active site, and leaves the protein conformationally and functionally intact. On denaturation, the absorption band of the new chromophore at 360 nm generates its own difference spectrum, in terms of which the kinetics can be measured. In temperature-jump experiments the dinitrophenyl group produces an effect in the microsecond range, which is simply a thermal perturbation in the chromophore itself, followed by a relaxation in the millisecond range, which is essentially identical with that observed when measurements are made at a tyrosine-sensitive wavelength either in the dinitrophenyl or unmodified ribonuclease. Again, the slow (rate determining) unfolding reaction, which is conveniently observed in pH-jump experiments in the acid-unfolding range, proceeds at the same rate irrespective of the wavelength. These results reinforce confidence in the procedure, and affirm that disparate parts of the molecule share the same folding pathway. Moreover the rapid phase of the reaction is observed only in experiments well within the temperature range of the folding transition, which confirms that they are identifiable with the folding process.

A deeper examination of the ribonuclease equilibrium is now possible. Tsong, Baldwin and Elson (*Proc. US Nat. Acad. Sci.*, **69**, 1809; 1972) have been able to show that the kinetics are consistent with a sequential process of nucleation and propagation, rather than a superimposition of incorrect, abortive folding reactions. Stopped-flow measurements of pH-dependent denaturation and refolding experiments

reveal a fast process in the folding reaction only in the lower part of the pH-transition range, whereas it persists over the whole range in the unfolding process under the same conditions. It is also important, and was demonstrated by Summers and McPhie (*Biochem. Biophys. Res. Commun.*, **47**, 831; 1972), and now reaffirmed by Tsong *et al.*, that above the transition zone the unfolding reaction can essentially be expressed by the fast process alone. This all follows expectation for a sequential model. No rapid steps preceding nucleation can be detected in the range where this step is dominant, and only a low extent of folding is achieved. The rate constant for the slow phase is the same in unfolding and refolding experiments. Experiment and theory for the sequential model can be matched for a series of kinetic criteria. Tsong *et al.* nevertheless urge caution. Although the results can be fitted well enough (although not necessarily uniquely) in terms of the usual set of independent thermodynamic variables, they point out that the implicit assumption of a set of rapid folding or unfolding steps with identical rate constants is unrealistic; that one cannot at this stage determine whether several pathways to the same end product may exist; that the further implicit assumption of a constant heat of unfolding is barely applicable in a complex situation involving hydrophobic and other forms of interaction with specific heat components, and finally that under some conditions, below the transition zone, an unexplained intermediate phase appears in the kinetics. As the rapid phase becomes dominant in the upper part of the range, one may entertain the hope that

Replication of Adenovirus 5 DNA

ALTHOUGH most microbial and viral systems in which DNA replication has been investigated in any detail have been found to contain circular replicative intermediates, it would be quite wrong to conclude that the generation of circular molecules is a universal step in DNA replication. For it is known that all the replicative intermediates of, for example, T7 coliphage DNA are linear and according to Sussenbach, van der Vliet, Ellens and Jansz, whose latest experiments are reported in next Wednesday's *Nature New Biology* (September 13), the same is true of replicating adenovirus 5 DNA molecules.

This Dutch group has devised a way of isolating the nuclei of KB cells infected by adenovirus 5 which continue to support the replication of the viral DNA *in vitro*. Various adenovirus 5 DNAs with sedimentation coefficients of 31S-60S and buoyant densities of 1.716 (mature viral DNA) to 1.724

g cm⁻³ can be isolated. The replicative intermediates with the high buoyant densities were found to contain single stranded DNA, which accounts for their buoyant density, and when they were separated from the non-replicating DNA and examined under an electron microscope they appeared to be linear molecules which fall into two chief classes.

One class contains Y shaped molecules, one arm of the Y being single stranded and the other arm and stem double stranded. The second class includes partially double stranded and partially single stranded, but unbranched, molecules. These and the various other forms can be explained by postulating that adenovirus 5 DNA replication starts at the end of one strand and is accompanied by the displacement of a strand; the displaced strand can then act as a template, either before or after it is completely displaced.

the folding intermediates may be susceptible to more detailed analysis.

The generality of the overall scheme is supported by a similar study by Tsong and Baldwin (*J. Mol. Biol.*, **69**, 145; 1972) on chymotrypsinogen A, also previously held to display a simple two-state denaturation equilibrium to a first approximation. Again a fast and a slow phase are resolved, which are the same in pH-jump and temperature-jump experiments, and it seems that here too a slow nucleation process co-exists with a rapid folding-unfolding reaction.

COSMOCHEMISTRY

Abundance Discussed

from a Correspondent

MUCH of the discussion at the Cosmochemistry Symposium held in Cambridge, Massachusetts, from August 14 to 16 was related to the cosmological implications of the studies of the abundances of particular nuclei in various astronomical objects. In particular, Dr H. Reeves (CNRS-Saclay) pointed out that nuclear astrophysicists believe that deuterium could only have been synthesized in the big-bang, the amount of deuterium produced being dependent on the density of the universe (independent of Hubble's constant) and the assumed lepton number of the universe. It was also felt that ^4He and possibly some ^3He and ^7Li were produced in the big-bang. Dr Reeves showed that the conditions necessary to do all the required nucleosynthesis implied that the density of the universe now is $\sim 2 \times 10^{-30} \text{ g cm}^{-3}$ and that the lepton number is possibly non-zero and slightly negative. These conclusions depend strongly on the D/H ratio for various objects.

Another cosmological use for measurements of isotopic abundance is in nucleocosmochronology where the relative abundances of radioactive nuclei are used to determine information about events near the time of formation of the solar system as well as time scales related to the total duration of nucleosynthesis and thus the age of the Galaxy.

In a review paper, Dr D. N. Schramm (University of Texas, Austin, Texas) emphasized that the relative abundance of ^{244}Pu was the factor determining whether any exceptionally large nucleosynthetic event occurred just before the solar system formed. It was mentioned that current chronologies are based on ^{244}Pu numbers from only one meteorite, the chondrite St Severin. Dr G. Crozaz (Brussels University, Belgium), Dr D. Burnett (Caltech, Pasadena, California), and Dr R. Walker (Washington University, St Louis, Missouri) presented results of fission track measurements which showed that U and Th are chemically fractionated in many meteorites.

It is reasonable that Pu would also be fractionated and therefore it is extremely dangerous to base nucleochronologies on the ^{244}Pu measurements from a single meteorite. In conjunction with nucleochronology, new interpretations were given for the time interval of 10^8 yr between the last nucleosynthetic event and the formation of the solar system. This time interval was once thought of as the time taken to form the solar system. The possibility that this time might better be related to the density wave theory of the galaxy was, however, given strong support by Professor A. G. W. Cameron (Yeshiva University), Dr D. N. Schramm, and Dr H. Reeves. According to this theory the interval of 10^8 yr represents the time between formation and when the protosolar gas was last being mixed with the gas in a spiral arm.

Apart from the application of abundance measurements to cosmology, an important area of cosmochemistry is its application to the special problems of

the formation of the solar system. An exciting discussion, principally involving Dr. P. Gast (NASA Manned Space Flight Center, Houston) and Dr D. L. Anderson (Caltech), centred on the formation and composition of the Moon. Dr Anderson showed that it was possible for the whole Moon to be formed from a single high temperature condensate with a composition similar to that of the inclusions in the Allende meteorite. This proposal greatly pleased people such as Professor Cameron, who felt that a high temperature condensate made for a more probable theory of the formation of the solar system.

Also of interest was the almost heretical proposal by Dr P. B. Price (University of California, Berkeley) that cosmic rays might possibly yield a more representative sample of the galactic material than does the solar system. This, of course, depends on the unscrambling of the propagation problem as well as a more accurate determination of charges and abundances.

Regulation of RNA Synthesis in Embryos

DURING embryonic development, the pattern of RNA synthesis changes markedly, indicating control of gene expression at the level of transcription. Ribosomal and transfer RNAs are specific molecules whose transcription can be studied directly, but the question of whether their synthesis is regulated during early embryogenesis remains controversial.

In next Wednesday's issue of *Nature New Biology* (September 13), O'Melia and Vिलее report results that will renew the argument. They present evidence showing that 5s RNA and tRNA are synthesized by embryos of sea urchins at the cleavage stage.

Until recently, it was generally accepted that, in several embryonic systems, synthesis of rRNA and tRNA did not occur during cleavage and became activated at about the time of gastrulation. This conclusion was based on the fact that when embryos incorporate radioactive nucleic acid precursors during cleavage, the RNA which they make is heterogeneous in size and has DNA-like base composition (dRNA). It consists predominantly of heterogeneous nuclear RNA and messenger RNAs. Synthesis of rRNA cannot be detected even with long labelling periods, and 4s RNA labelling is largely CCA turnover (for example, Gross, Kraemer, and Malkin, *Biochem. Biophys. Res. Commun.*, **18**, 569; 1965). By contrast, when gastrula or later stages are labelled, newly synthesized rRNA and tRNA are readily detected. Synthesis of dRNA continues, but at a reduced rate per nucleus. It has, however, been pointed out that the rapid

synthesis of dRNA during cleavage could obscure rRNA synthesis even if this occurred at the rate seen in older embryos (Emerson and Humphreys, *Dev. Biol.*, **23**, 86; 1970). This, of course, does not prove that rRNA synthesis does occur early. Only circumstantial evidence has been presented, and most of the evidence argues against this interpretation (Sconzo and Giudice, *Biochim. Biophys. Acta*, **254**, 447; 1971, for example).

What O'Melia and Vилее have done is to concentrate on tRNA and 5s RNA, which they purified by precipitating larger RNAs with 2 M LiCl. Also, by using guanosine as a precursor, they avoided CCA end-labelling, as guanosine is not converted to other nucleotides. In this way, they detected *de novo* synthesis of tRNA and of 5s RNA during cleavage. The two RNAs were identified by polyacrylamide gel electrophoresis and, using an exonuclease, they showed that the label was internal. The tRNA, but not the 5s RNA, also became methylated.

Thus synthesis of tRNA and 5s RNA is not completely switched off during cleavage. What then of the other rRNA species whose synthesis is generally coordinated with that of 5s RNA? Either they are also synthesized or this system is an exception and coordinate synthesis does not occur. Unfortunately, O'Melia and Vилее present no data on the fraction of total RNA synthesis which is represented by tRNA plus 5s RNA, so it is not clear whether there is a low level of synthesis or one equivalent to that seen later in development.

GENETICS

Promoting Gene Activity

from our Molecular Genetics Correspondent

WITH the mechanisms by which operons are switched off by repressor proteins becoming well characterized, one of the most pressing problems in regulation of gene expression is to define the interaction which takes place between RNA polymerase and the promoter of an operon to allow its transcription into RNA and hence translation into proteins. The discovery that at least one promoter of phage λ comprises a complex structure, with a site where RNA polymerase binds separated by 200 nucleotides from the site where transcription is initiated (see *Nature*, **237**, 426; 1972), shows that the sequence of events leading to expression of the genes of an operon may be a complex one.

The promoter of the lactose operon also appears to comprise two sites, as Beckwith, Grodzicker and Arditti report in the *Journal of Molecular Biology* (**69**, 155; 1972), although in this case they seem to lie adjacent to each other. Several different mutations in the region between the *i* regulator gene and the operator of the lactose operon reduce the level at which the enzymes of the operon can be produced; these have been taken to define the site at which expression of the operon is initiated. Two proteins must interact at this initiation site if the lactose operon is to be switched on; RNA polymerase must bind to the site to initiate synthesis of RNA, but this action depends on the presence of a further protein, the cyclic AMP binding protein, which is activated by the cyclic nucleotide.

A deletion in the left end of the promoter reduces transcription of the operon to 2 per cent of its usual level, but this residual activity does not depend on mediation of the cyclic AMP system. This suggests that RNA polymerase can bind to the right end of the promoter, albeit weakly, of its volition, and can initiate transcription there. And mutants which lack an active cyclic AMP system can also express the operon at this low level, presumably by utilizing only this part of the promoter. But these strains, which either lack an active cyclic AMP binding protein or which cannot synthesize cyclic AMP, might be leaky so that residual expression depends on this system after all. By constructing double mutants, which can neither make cyclic AMP nor utilize added cyclic AMP, Beckwith *et al.* have excluded this possibility and have shown conclusively that the lactose operon can be expressed at 2 per cent of its usual level without mediation of the cyclic AMP system.

The immediate prediction suggested by these results is that mutants should

exist in the right end of the promoter which do not influence the interaction with the cyclic AMP system, but which reduce initiation of transcription of the operon. It is the properties of these mutants that will solve a long standing question: does the sequence of the promoter where RNA polymerase binds overlap that of the operator where repressor protein binds? Biochemical experiments have suggested that RNA polymerase and repressor do not compete for binding to DNA, but that repressor acts as a block to the progress of polymerase into the structural genes of the operon. The genetic conclusion—which seemed to buttress this idea—that promoter mutants do not influence the activity of the operator now seems, however, to have been based on the use of mutants which affect only the activity of the cyclic AMP binding system. It is mutants which affect the binding of polymerase which must now be used to re-investigate this idea.

To discover the sequence of DNA base pairs which makes up the promoter and operator is, of course, one of the most important experiments to be performed; but attempts to protect DNA by binding these proteins to it so that the binding sites can be recovered and sequenced have not proved successful. A more subtle approach to deducing the sequence of a promoter is offered by the results now reported by Jackson and Yanofsky (*J. Mol. Biol.*, **69**, 307; 1972), who have mapped the internal promoter of the tryptophan operon in its second gene.

In cells which are repressed for the tryptophan enzymes, the first two genes of the operon are inactive, but the last three are expressed at a low level because a weak promoter seems to be located within the operon. Genetic mapping experiments now show that this site is located close to the end of the *trpD* gene, the second of the five tryptophan genes. This means that a sequence

of DNA which codes for protein must also act as a site for binding RNA polymerase and initiating transcription. If mutants in this promoter can be isolated, characterizing the sequence of the protein which is made and comparing it with the wild type enzyme may reveal the nucleotide sequence which makes up this recognition region. Sequencing DNA directly seems unlikely to resolve promoter and operator sequence; and if the sequence of the tryptophan operon promoter can be deduced in this way, it will no doubt not be long before genetic tricks are used to turn other regulator sequences into proteins which can be sequenced.

MID-ATLANTIC RIDGE

Conflict at 43° N

from our Geomagnetism Correspondent

THE spreading history of the mid-Atlantic ridge at latitude 43° N is in doubt because there is a conflict between magnetic anomaly evidence and plate tectonic evidence. If the magnetic anomaly profile at that latitude is to be consistent with seafloor spreading, the spreading rate out to 30 km (4 million years) from the ridge crest and beyond 150 km (11 million years) must have been about 0.75 cm yr⁻¹, whereas between 30 and 150 km it must have been about 1.65 cm yr⁻¹. In short, there was apparently a period of about 7 million years when the rate of spreading more than doubled. Plate tectonic evidence, on the other hand, indicates no such anomaly. If plate motions based on the strike of fracture zones and spreading rates extrapolated from other parts of the ridge are used to calculate the spreading rate at 43° N, the answer turns out to be about 0.75 cm yr⁻¹, whether the extrapolation is from the South Atlantic or from the Reykjanes ridge and the Arctic Ocean.

Another Way to Reduce Drag

ALTHOUGH it is well known that drag in turbulently flowing liquids can be reduced by adding polymer solutions, soap solutions or even solid suspensions to them, each additive has its own particular disadvantage. Polymer solutions, for example, are quite easily degraded mechanically.

In *Nature Physical Science* next week (September 11), Zakin and Chiang report that yet another type of additive—a non-ionic surface active agent together with a salt—can reduce drag, and that it is both mechanically and chemically stable. The particular surface active agent used was a mixture of polyoxethylene and two saturated hydrocarbons.

Tests on a 1 per cent solution of the agent in water, containing varying amounts of Na₂SO₄, revealed significant drag reduction at Na₂SO₄ normalities greater than about 0.3. With 0.3 and 0.35 N solutions drag reduction dropped off at the higher Reynolds numbers but 0.4 N solutions displayed both the greatest relative viscosity (2.80) and the greatest drag reducing capability in any of the experiments. (A drag reduction of 57 per cent was measured at a Reynolds number of 11,000 under these conditions.) At higher concentrations of the salt, the drag reducing behaviour was little altered, but the viscosity was considerably smaller (1.60 at a normality of 0.50).

Of course, 43° N is the latitude at which the boundary between the African and Eurasian plates meets the mid-Atlantic ridge, and so life there is not likely to be easy. Even so, the fact is that the supposed change in spreading rate 4 million years ago is observed in neither plate.

How, then, may this controversy be resolved? Kasameyer *et al.* (*J. Geophys. Res.*, **77**, 2535; 1972) have apparently succeeded by turning to experimental and theoretical studies of heat flow and bathymetry. The experimental data were obtained during a crossing of the ridge at 43° N by the research vessel Atlantis 2, the heat flow profile being the first ever taken across the mid-Atlantic ridge between 25° N and the Reykjanes ridge. In general, this profile is typical of oceanic ridge heat flow profiles. Thus the eight values of heat flow obtained at distances greater than 500 km from the central rift were uniform, all lying within 8 per cent of $1.45 \mu\text{cal cm}^{-2} \text{ s}^{-1}$ (h.f.u.). This average is significantly higher than the 1.1 to 1.2 h.f.u. previously given for the North Atlantic (but with few values north of 40° N), but is not out of line with that for the equatorial Atlantic. The eight values obtained within 120 km of the central rift were, however, higher on average (3.4 h.f.u.) and more variable (0.6 to 7.2 h.f.u.). On the other hand, the new profile differs from a typical profile in one important respect. At distances of 100 to 300 km from the crest it lacks symmetry, values in the west being some 60 to 80 per cent higher than in the east.

On the theoretical side, Kasameyer and his colleagues have adopted a model put forward some years ago by McKenzie (*J. Geophys. Res.*, **72**, 6261; 1967) which makes possible the determination of heat flow and increased elevation caused by the creation of new lithosphere at the ridge crest. On the assumptions that the spreading rate is constant and that the temperature at the centre of the lithosphere is the same as that at the bottom, this model gives a steady-state heat flow equation which contains terms representing the heat carried by the moving slab and the heat transmitted by conduction. The temperature gradient at the surface is then used to calculate the extra heat flow (as a function of distance from the crest) due to the intrusion of hot magma into the lithosphere; a constant coefficient of thermal expansion is assumed in predicting the elevation.

Experience in the south Atlantic shows that this thermal model, although simple, predicts both bathymetry and gravity that agree well with reality; and so Kasameyer *et al.* feel justified in using it to solve the problem at 43° N. Complications arise, however, in cases where the spreading rate is not constant. In such situations it is necessary

to seek an approximate solution to the heat flow equation by assuming that all heat is carried away from the ridge by the moving slab—in other words, carried heat and vertical conduction are allowed, but horizontal conduction is considered negligible. As it turns out, this condition is not particularly restrictive. The simplified heat flow equation thus produced is highly insensitive to spreading rate (at least over the range 0.75 to 2.00 cm yr⁻¹), and has the advantage that the heat flow and elevation predicted from it depend only on the time since intrusion. In short, “the thermal history of a section of lithosphere depends on its age alone, not on the spreading history of the ridge. The thermal history is frozen into the lithosphere, much as the magnetic anomalies are frozen into the lithosphere.” This means that Kasameyer and his colleagues have been able to plot predicted heat flow and bathy-

metric profiles for 43° N based on the magnetic anomaly version of events, on the one hand, and based on the plate tectonic version, on the other. In other words, variations in spreading rate are accommodated easily by predicting heat flow and bathymetry at any given point solely from the age of the lithosphere there.

So what happens when predicted and observed profiles are compared? In practice, it turns out that the heat flow profiles are unsuitable for this comparison, partly because the predicted shape is not greatly affected by the 7 million year period of high spreading rate, partly because of difficulty in accurately determining the base line (even far from the ridge the excess heat flow due to lithospheric intrusion may not be negligible), and partly because the observed profile may be distorted by non-conductive heat transfer processes such as the circulation of water and

Detecting Human Anti-CEA Antibodies

CARCINOEMBRYONIC antigen (CEA) was first detected by Gold and Freedman in 1965 (*J. Exp. Med.*, **121**, 439) in adenocarcinomas of the human alimentary tract and in early foetal gut. It is a glycoprotein and a probable constituent of the tumour cell glycocalyx. The current clinical interest in CEA for the immunodiagnosis of cancer depends on the fact that this substance can be detected by a variety of radioimmunoassays in the peripheral blood of patients with cancer of the digestive system. When first describing it, Gold and Freedman referred to CEA as a tumour-specific antigen. By analogy with experimental animal tumours one would therefore expect CEA to evoke the appropriate specific responses in the host. The evidence on this point has so far been contradictory. In 1967 Gold (*Cancer*, **20**, 1163) claimed that 70 per cent of patients with gut tumours and 70 per cent of pregnant women had in their serum an IgM anti-CEA antibody. These results were obtained with a somewhat unsophisticated haemagglutination technique. Burtin and his group (*Immunology*, **10**, 507; 1966) showed, however, that such antibodies could be removed from the serum by absorption with normal gut extracts.

In next week's *Nature New Biology* (September 13) Gold, Freedman and Gold report a series of experiments using a very sensitive method for detecting antibodies, based on radiolabelled CEA. Their method involved mixing ¹²⁵I-labelled CEA with the test serum for 48 h, and then subjecting this mixture to immunoelectrophoresis with subsequent autoradiography. They examined 92 sera obtained from patients and normal healthy individuals. The presence of

antibodies reacting with the labelled CEA was readily confirmed in both cancer patients and in normal subjects. The presence of these antibodies, predominantly IgM, appeared to correlate with ABO blood group status. Of 56 sera from individuals of blood group O or B, 80 per cent contained detectable antibody. Of the remaining 36 sera from subjects of groups A and AB, only 19 per cent contained anti-CEA activity. The sera were then absorbed with group A erythrocytes and the assay repeated. In the group O and B sera the anti-CEA activity was removed by absorption in all but two. In the A and AB population the activity was not affected. Purified human anti-A antibody was shown to react with CEA. Monospecific goat anti-CEA antiserum did not, however, react with blood group A substance. The sera from which anti-CEA activity was not absorbed out with group A red cells were all from patients with disseminated cancer.

These findings indicate an extensive cross-reaction between blood group A substance and their preparation of CEA. Antibody titration experiments suggest that this is a genuine cross-reaction, and was not due to contamination of the CEA preparation. But as the principal immunoreactant in A substance, N-acetyl D-galactosamine, is absent from CEA, simple explanations for the cross-reactivity will not suffice. The authors even postulate that the group A reactivity may be an artefact.

The presence of anti-CEA antibodies, not absorbed by group A red cells, in the sera of some cancer patients lends weight to the idea that CEA is a tumour-specific antigen and that it may even play a part in host resistance.

magma. The bathymetry profiles, on the other hand, suffer no such disadvantages—the 7 million year anomaly has a significant effect, the base line (the depth of the oceanic basement away from the ridge) is well known, and the observed profile, being continuous, easily distinguishes local topographic perturbations.

What emerges from the bathymetric comparison is that the model involving a constant spreading rate (the 0.75 cm yr^{-1} rate from plate tectonics) wins, at least south of a fracture zone (75 km offset) which crosses the survey region. Here, between 30 km and 150 km from the central rift, there is insufficient elevation to accommodate a doubling of the spreading rate for 7 million years. For at least the past 40 million years the spreading rate has apparently been less than 1.0 cm yr^{-1} .

North of the fracture zone the situation is quite different, for not even the plate tectonic interpretation applies. To the south, plate tectonic predictions of topography and heat flow agree with observations, but to the north neither do. Within 150 km of the central rift the topography is too flat. Between 200 and 500 km to the east, it is too high; but the heat flow there is low, which means that if the high elevation is to be explained by thermal expansion the temperature gradient must increase rapidly within the upper few km.

HORTICULTURE

Fusarium Patch Disease

from a Correspondent

AFTER a dry few weeks, lawns in Britain are not looking at their best and, even though autumn rain and applications of fertilizers will restore most turf to a better condition, excessive use of water and fertilizer can easily lead at this time of the year to an outbreak of fusarium patch disease.

This disease, which is caused by *Fusarium nivale* (Fr.) Ces., is one of the commonest and most damaging diseases of turfgrass in Britain. Outbreaks of the disease can take place in any season, but it is most prevalent in spring and autumn. Humidity, especially at the turf surface, is one of the principal factors at the infection stage of the disease, which is more likely to occur in shaded areas than in warm and overcast conditions. Layers of moist fibre in the surface of the turf encourage infection and usually the first symptoms are yellowish brown patches approximately 1 to 2 inches in diameter. These patches can spread and the disease increases in severity very rapidly if environmental conditions are favourable. In one or two days widespread and severe damage can occur with the possibility of the grass being completely destroyed.

Examination of dying plant parts behind the advancing edge of the mycelium readily reveals large numbers of the sickle-shaped spores which are often formed in sporodochia. These spores are easily carried on the feet, on grass clippings and on machinery and can give rise to fresh outbreaks. The life of the spores seems to be fairly short, and it may be that the original infections take place by development of aggregations of mycelium embedded in grass leaf residues.

The bare areas produced by the disease are very unsightly, and leave the turf open to invasion by dicotyledonous weeds and undesirable grass species. A grass which commonly fills the bare areas is annual meadow-grass (*Poa annua* L.), which, unfortunately, is particularly susceptible to fusarium patch disease. The presence of this species in many fine turf areas increases the risk of disease and although other species of grass used in turf, including browntop (*Agrostis tenuis* Sibth) and red fescue (*Festuca rubra* L.) can be attacked, *P. annua* is often the first to be infected. Some varieties of perennial ryegrass (*Lolium perenne* L.) are, however, moderately resistant.

In general, increasing nitrogen levels result in an increase in the infection. The disease spreads following the use of fertilizers such as sodium nitrate and nitro-chalk, which tend to make the turf more alkaline. The time at which fertilizer is applied is also important and treatment with any fertilizer that gives readily available nitrogen in September often leads to rapid development of the disease if the weather conditions are favourable. In this case the grass growth is often very lush and the leaves are rather susceptible to mechanical damage.

Treatment with fungicides can prevent infection and control the disease after it has begun to develop. Fortunately most of the fungicides sold for use on turf in Britain are effective because this disease is one they must control to be commercially viable.

The pattern of disease development described is not the only one possible. Occasionally in Britain, but more frequently in Northern Europe and North America, *F. nivale* is responsible for "pink snow mould", a condition where infection and development take place under snow cover. In this case damage to the turf is revealed when the snow melts, and often mycelium of the fungus can be seen among the dead grass.

SOLID STATE

Penetrating Fields

from a Correspondent

IN a new calculation of the capacitance of two metal plates separated by a vacuum, Theophilou and Modinos (*Phys. Rev. B*, **6**, 801; 1972) have managed to avoid making the assumption that charge terminates abruptly at the metal-vacuum interfaces and have shown that the capacitance arising at the interface because of penetrating electric fields is negligible.

As every student of physics knows, the capacitance of a parallel plate capacitor depends on the inverse of the distance between the plates. This honourable result of classical electrostatics remained unassailed until quite recently, when Mead (*Phys. Rev. Lett.*, **6**, 545; 1961) observed that the capacitance of very thin Ta-Ta₂O₅-Au sandwiches deviated from the expected value, and that if the plate separation was extrapolated to zero, the capacitance did not

Faraday Rotation in Radio Galaxies and Quasars

The origin of the polarization of extragalactic radio sources is tackled in next Monday's *Nature Physical Science* by R. G. Strom of Leiden Observatory. He has used observations of the linear polarization of a number of sources to examine the relationship between the linear diameter of the sources and the product of the line-of-sight magnetic field and the integrated electron density.

The linear diameter is simply obtained from a consideration of the angular diameter and the redshift, assuming the redshift to be cosmological. The product of the magnetic field and the electron density, on the other hand, is obtained on the assumption that the Faraday effect occurring within the sources is responsible for the observed dependence of linear polarization on wavelength.

Strom has plotted these two quantities for twenty-eight radio galaxies and

twelve quasars. By assuming that each electron contributing to the electron density comes from an ionized hydrogen atom it is possible to use this plot to obtain for the sources the product of the mass of ionized hydrogen which they contain and the line-of-sight magnetic field. According to Strom this product for about half the sources is $10^{23 \pm 0.5} M_{\odot}$ gauss. Typical values for the parameters involved in the product may be $10^7 M_{\odot}$ for the mass of ionized hydrogen and 10^{-5} gauss for the line-of-sight field.

An interesting feature of Strom's plot is the general similarity which it shows between the values of the product (mass of ionized hydrogen) $\times$ (line-of-sight magnetic field) for quasars and for radio galaxies. This is of course based on the assumption that the quasar redshifts are cosmological, and Strom says that if, to the contrary, quasars are nearby objects, the good agreement is lost.

become infinite but only about 0.03 F m^2 . Mead attributed this deviation to the penetration of the electric field into the metal, giving rise to an effective capacitance at each metal-insulator interface. Ku and Ullman (*J. Appl. Phys.*, **35**, 265; 1964) supposed that the electronic charge terminated abruptly at the metal surface, and they obtained reasonable agreement with Mead's results. Mott and Watts-Tobin (*Electrochim. Acta*, **4**, 79; 1961) assumed, however, an exponential decay of the electric field into the metal surface and found that although field penetration adds about 0.05 nm to the electrode spacing, it does not contribute a capacitance to the interface.

Recently other workers have joined the debate, working with a metal-vacuum rather than a metal-insulator interface. Tsong and Müller (*Phys. Rev.*, **181**, 530; 1969) assumed an abrupt termination of electronic charge in the same way as Ku and Ullman, and came to a similar conclusion that the metal-vacuum interface has a capacitance which significantly affects a parallel plate capacitor. Now Theophilou and Modinos have found that the capacitance at the interface can be ignored. If they are right, it is not possible to explain Mead's results in terms of field penetration. Clearly what is really being discussed is not the capacitance of a parallel plate capacitor, which is involved only as an interesting result of the authors' theories, but rather the abruptness or otherwise of the change in electric field at the surface of the metal. While the theoreticians sharpen their pencils in readiness for the next round, it is interesting to consider what effects the outcome of the debate may have.

The most important application, apart from the study of thin film capacitors, is in field ion microscopy. The specimen in a field ion microscope is subject to an intense electric field ($\sim 10^{10} \text{ V m}^{-1}$), and field penetration, together with the related effect of surface atom polarization, can change the binding energy of a surface metal atom or of a foreign atom adsorbed on the surface. When operating a field ion microscope it is sometimes necessary to evaporate the surface atoms by means of an electric field, that is to raise the electric field sufficiently to overcome the binding energy so that the surface atoms are evaporated in a controlled manner. When an alloy is field evaporated, it is usual for one element to evaporate more easily than the other, and this effect—selective evaporation—is of crucial importance in the interpretation of alloy images. If the binding energy of a surface atom is altered by field penetration, the field evaporation behaviour is also altered, and it is important to know the magnitude of this change. Fortunately for field ion microscopists,

the results of both Tsong and Müller and of Theophilou and Modinos are qualitatively similar, so whatever the outcome of their debate, the resulting corrections to field ion theory should be fairly small.

EPIDEMIOLOGY

Hepatitis and Flying-pins

from a Correspondent

THE epidemiological concepts of hepatitis B infection (serum hepatitis) have recently undergone a significant change (see a review by Zuckerman, *Hepatitis-associated Antigen and Viruses*, North Holland; 1972). The demonstration that type B hepatitis virus was infective by mouth and the finding that the infection was endemic in closed institutions, the prevalence of infection in adults in urban communities, the carrier rate and age distribution of hepatitis B antigen (Australia antigen) in different geographical regions and the relatively high incidence in poor socio-economic environments, have altered the epidemiological dogma that type B hepatitis was spread exclusively by blood and blood products through the parenteral route. There is also some evidence for the transmission of type B hepatitis by intimate personal contact and possibly by the sexual route. Although the modes of transmission of this infection in the tropics are similar to those in other parts of the world, other factors may be of importance. These include traditional tattooing and scarification, ritual circumcision and repeated biting by blood-sucking arthropod vectors.

Preliminary results of investigations into the role which biting insects may play in the spread of type B hepatitis are conflicting. No consistent association could be found between the notification of hepatitis and the months of high or low rainfall or with the period immediately after the rains in eight countries in Africa and Latin America (Cockburn, *Amer. J. Dis. Child.*, **123**, 346; 1972). Although this does not exclude the possibility that biting insects may play a role in the spread of hepatitis, these observations imply that those mosquitoes which multiply with the rains may not be involved.

In another study, in New Guinea, the incidence of hepatitis B antigen was compared, in the same population, with that of antibody to several arboviruses of groups A and B (Hawkes *et al.*, *Amer. J. Epidemiol.*, **95**, 228; 1972). The incidence of arbovirus antibodies correlated strongly with that of mosquito activity, and it was inversely related to altitude. On the other hand, the incidence of detectable hepatitis B antigen was not related to either mosquito activity or to altitude. The prevalence of arbovirus antibodies in the population also in-

creased cumulatively with age, whereas the incidence of hepatitis B antigen did not increase significantly with age. Moreover the different prevalence rates of antigen among ethnic groups living in the same geographical areas are inconsistent with vector-borne infection.

There is one report, however, which is yet to be confirmed, that some species of mosquitoes may serve as biological vectors for type B hepatitis infection (Smith *et al.*, *Nature*, **237**, 231; 1972). Colonies of *Anopheles gambiae*, *Culex pipiens fatigans* and *Aedes aegypti* were maintained from the egg to the adult stage. Newly emerged mosquitoes were starved for two days and later fed experimentally on blood with and without hepatitis B antigen. Surprisingly, the *Anopheles* and *Aedes* species refused to feed on such blood and died of starvation, although the controls did feed on blood without the antigen. Hepatitis B antigen was found by the immunofluorescent antibody technique in the lumen of the gut of the mosquitoes immediately after feeding on antigen-positive blood, and the antigen persisted in the lumen of the gut for ten days. Antigen reappeared in the salivary glands after three weeks. The antigen was also detected in the lumen of the gut and the salivary glands of infected culicine mosquitoes that died after eight weeks. More recently, 187 pools of mosquitoes caught in the wild in Kenya and Uganda were tested for hepatitis B antigen using the solid-phase radioimmunoassay technique (Prince *et al.*, *Lancet*, **ii**, 247; 1972). The antigen was detected in twenty-eight pools of mosquitoes representing eight different species. The trapped mosquitoes were from human bait collection and would therefore be likely to feed on human hosts. *A. aegypti* mosquitoes were also fed experimentally on a human chronic carrier of hepatitis B antigen and on a healthy subject, and the rate of disappearance of detectable antigen was investigated in the mosquitoes, which were subsequently maintained at 30°C . The antigen disappeared in parallel with blood meal digestion.

Mosquitoes in the tropics feed every two or three days and, if feeding on man, mosquitoes in certain tropical zones have at least a one in ten chance of feeding on blood containing hepatitis B antigen, because of the high prevalence of this antigen in the indigenous human population. It is considered possible, therefore, that mosquitoes may play a mechanical or a passive role in the spread of hepatitis B infection. As a corollary, other orders and families of blood-sucking arthropods may play a similar role and further studies are required. A new dimension has thus been added to the epidemiology of hepatitis B infection in man.

Gravity Waves in the Atmosphere

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Atmospheric gravity waves similar to waves that occur on the surface of a body of water have been known since the nineteenth century, but their significance for the study of atmospheric dynamics has been realized only in the past ten years.

GRAVITY waves at the surface of the sea are constrained to propagate horizontally. In their elementary form, their vertical variation consists simply of an exponential decay of amplitude away from the abrupt interface that gives them their being. They may be termed, for identification, "evanescent". Similar waves can often be found at depth in the oceans at an interface between waters of different origin (having different temperature or salinity, for example, and hence different densities—the lighter will overlie the heavier, and so provide a density discontinuity analogous to that at the surface). Evanescent waves at the interface propagate horizontally along it, with amplitudes that decay exponentially away from it. Whenever the density of the water varies continuously with height, the evanescent waves may be joined by members of an identifiably different type, which may be termed "internal". Their essential distinction is that they are no longer constrained to horizontal propagation, but may progress obliquely upwards or downwards in the fluid.

Waves in the Atmosphere

The atmosphere for its part is always structured by the pull of gravity in such a way that its density decreases continuously with increase of height. It is able to support gravity waves, both of the evanescent and of the internal type, analogous to those of the oceans. Both are important, and for many purposes no distinction need be made, but I shall put special emphasis on the internal waves because of certain of their ancillary properties. For example, because the internal waves carry energy (obliquely) upwards or downwards, they carry it to regions of different gas density. Upward propagation carries energy to regions where fewer gas molecules are available to carry the energy onwards, and these molecules can accomplish their task only if they oscillate with greater amplitude. Thus it is an intrinsic feature of internal atmospheric gravity waves that they tend to grow stronger the further they rise above their source. This behaviour may be more than offset initially by simple geometrical spreading and dispersion along the path, but the inherent growth follows an exponential pattern and must ultimately come to dominate unless other processes intercede. Important special effects result. (A partial analogue is to be found in ocean waves as they approach a sloping beach. Their energy is carried by an ever diminishing depth of water, and their amplitude grows in response. The special effects in this case include the formation of surf on typical occasions, and the growth of "tidal waves" in more extreme circumstances.)

The propensity for exponential growth of amplitude with height in the atmosphere is shared by a second class of internal atmospheric waves—ordinary sound waves. Some relationship between sound waves and gravity waves may be glimpsed if the effect of gravity is added to the usual description of sound waves as waves of compression and rarefaction: the compressed regions in the sound wave, being denser than their surroundings, tend to fall, while the rarefied regions, being more buoyant, tend to rise. The resulting modifications are of little consequence at the relatively high frequencies of oscillation that we detect as sound, but when the period of oscillation extends to a minute or more they become important. At periods that exceed a certain resonant value, lying typically in the range 5 to 15 min in our atmosphere, the nature of the oscillation changes abruptly. It is then that we alter our nomenclature, and speak of "gravity waves". The combined spectrum, including evanescent as well as internal waves, is occasionally termed the "acoustic-gravity" wave spectrum.

A further transition occurs at longer periods of oscillation, when the Coriolis force associated with the Earth's rotation becomes important. This force merely modifies the elementary gravity waves, at periods of a few hours, but at sufficiently longer periods it converts them to a new and distinctive class of waves that has been termed "rotational". This first comes into being at a period of 12 h (sidereal) in the immediate vicinity of the north and south poles, but its existence as an identifiable class spreads towards the equator as the period of oscillation lengthens. At periods of a few days, gravity waves are confined to a limited belt near the equator, and even there they are mixed with rotational waves. The latter dominate at middle latitudes, where, modified by the background circulation of the atmosphere, they form "Rossby" or "Rossby-Haurwitz" or "planetary" waves. These in turn modify both the background circulation and, of course, the weather. Some of their effects are seen in the progression of pressure systems recorded daily on meteorological maps, while others are hidden in more subtle ways that defy such casual detection. For our purposes, however, they simply represent a long-period complement to the family of gravity waves, just as sound waves provide a short-period complement.

Emergence and Impact

Atmospheric gravity waves first appeared in the literature in the nineteenth century, but with conceptual and mathematical limitations that hampered their elementary identification, characterization and exploitation. They emerged explicitly as a mathematically distinct type of wave some forty years ago¹, but made little immediate impact on the study of atmospheric dynamics. Their rise from obscurity was slow, and was confined initially to a single area of application. This concerned "mountain lee waves"—updrafts and down-drafts which are engendered by mountain ridges and hills as the surface winds flow over them, and which persist for some distance downstream and extend to some height. These waves had already been utilized intuitively by glider pilots—and by birds—but their mathematical analysis had not pre-

viously been undertaken. When it was, it perforce used atmospheric gravity waves and conveyed to them the respectability of relevance. Because mountain waves can be dangerous to aircraft, and because on occasion they generate intense "rotors" that can raise roofs from houses or topsoil from farms, it came to be recognized that atmospheric gravity waves were of direct significance to man.

This recognition spread gradually during the 1950s into other areas of application. Atmospheric gravity waves were observed at the coast of California, in circumstances that precluded their generation as mountain lee waves; they seemed instead to involve meteorological conditions of a particular sort. Similar waves were invoked in tentative but initially abortive attempts to explain the characteristics of certain wavelike disturbances that sweep across continents at heights of 250 km and more in the ionosphere. And behind the screen of military secrecy, a profound interest developed in gravity waves that were found to be triggered by nuclear detonations in the atmosphere, and whose characteristic waveforms carried useful information to friend and foe alike.

A more general perspective on the role of atmospheric gravity waves developed in 1960. It was initiated in part by Eckart², with the publication of a monograph that brought to a wide audience the systematic analysis of waves in oceans and atmospheres. Eckart's mathematical analysis had an elegance of its own, but it also led him to pick out for special attention one of the properties that distinguishes internal atmospheric gravity waves so markedly from their acoustic cousins: the oscillatory motions they produce are accompanied by only minimal variations of pressure. "This," he pointed out, "is also a characteristic of the fluctuations of wind velocity that occur without marked pressure fluctuations. One may therefore make a tentative identification of the gravity waves with the fluctuating component of the wind." This very identification had been made and proven in the Californian observations, but only with respect to special occasions when sinusoidal variations were detected. The suggestion now was much broader in scope, and opened a vast conceptual horizon: since fluctuations of wind occur throughout the atmosphere, it became appropriate to suspect that gravity waves do likewise.

Precisely this view was pressed at the same time by Hines³, on a different but fully complementary line of argument. During the preceding ten or fifteen years, both the neutral gas and the ionization of the upper atmosphere had revealed a wide variety of irregularities and motions. There were the wavelike ionospheric disturbances already mentioned, which occur with fronts 1,000 km long, speeds of progression up to some hundreds of m s^{-1} , vertical amplitudes of oscillation exceeding 10 km on occasion, and, the key to it all, periods of oscillation typically in the range 20 to 100 min. There were myriad lesser disturbances of the ionization, which had evoked in many a picture of wind-blown or electro-dynamically driven turbulence. There were direct measurements of irregular winds in the neutral gas at heights of 75 to 100 km, with typical speeds of 10 to 30 m s^{-1} ; and yet others of structure in noctilucent clouds at similar heights on a spatial scale of several km. Hines showed that all of these could be explained quantitatively, in their gross features at least, by a single basic mechanism: atmospheric gravity waves, primarily in their internal form, manifesting themselves sometimes in the fluctuating winds they produced and sometimes in the propagation of their waveforms. (The oceanic analogues of these motions are the bobbing of a cork as wave crests and troughs pass by, and the progression of those crests and troughs from one place to another.) Sources for the required waves could only be guessed, but the intrinsic exponential growth of amplitude with height suggested strongly that they might well have their origins as much less obvious waves at lower levels in the atmosphere. And because the various upper atmospheric phenomena were considered to be

generally present rather than generally absent, the suspected generation at lower levels had to be viewed as a common and perhaps widespread feature of those levels. In short, the atmosphere from its lowest levels to its highest must be suspected of being permeated by gravity waves.

Controversy and Advance

This interpretation of upper atmospheric processes, and its implications, provoked controversy from the moment of its introduction. To some extent previous notions were being challenged. The irregular winds, for example, had often been attributed to turbulence and were normally analysed (if at all) on that basis; but they were now to be taken as a superposition of relatively sinusoidal oscillations, and their irregularity was to be attributed to the wide variety of such oscillations that happened to be superimposed in the region of observation. Again, the wavelike ionospheric disturbances appeared to have a downward component of progression which had been suggestive of generation at some higher level; but this appearance was now to be attributed to a sort of optical illusion that is intrinsic to internal gravity waves, whereby individual ripples progress downward only if the region that is rippled (and hence the region that contains the energy at any given moment) is rising from some source at lower levels. Beyond the challenge to prior notions came the broad sweep of the claims being made for the role of gravity waves in the upper atmosphere: to many it was simply too much to accept, at least in one fell swoop, while to others it came as a natural and suddenly obvious consequence of the exponential growth of amplitude with height. To some, again, the occurrence of internal gravity waves in the real atmosphere was a concept to be challenged except in the face of unequivocally identified sources; to others, their occurrence was now clear and the question of sources was but one of the many that had been opened to inquiry.

The decade that followed witnessed a truly remarkable growth of gravity-wave studies. Observational programmes were instituted and earlier data were re-analysed, to test the hypothesized occurrence and extent of these waves. Other observational programmes, designed quite independently at an earlier date, came to fruition and added their own contribution of relevant data. Diverse techniques, probing low altitudes and high, revealed a dynamical state that could often be interpreted as a superposition of waves, and one that occasionally exposed unambiguously wavelike components. It became common practice to seek a fit with gravity-wave theory. That theory in turn developed at a rapidly accelerated pace, outstripping the observations in some areas and being pressed by them in others. It fed, and fed on, related studies of oceanic gravity waves and of atmospheric tides and planetary waves. Most important of all, perhaps, the conceptual areas of interest were continually being broadened: as the ubiquitous nature of gravity waves came to be confirmed, so their relevance to a multitude of other phenomena came to be recognized.

I cannot hope to review this decade of growth in any detail here. I cannot expose the intimate interweaving of observational and theoretical advance, for example, nor explore in any depth the interdisciplinary interactions that have proven to be so profitable. Instead, I must be content with a superficial skimming and a representative referencing.

Upper Atmospheric Observations

One pressing need from the outset was an unambiguous confirmation or rejection of the basic gravity-wave interpretation of upper atmospheric motions. Support emerged from several investigations. Irregular vertical variations of temperature at heights of 75 to 100 km were found to exhibit amplitudes that match those of the irregular winds, when the two were linked by gravity-wave theory, and they revealed

the vertical progression that could be expected of internal waves. The irregular winds were analysed in greater detail with the aid of improved radars that detected moving meteor trails in profusion, and cyclical components of motion were thereby revealed. Their periods lie well within the gravity-wave range and their amplitudes exhibit an exponential growth with height at a rate very close to that predicted by theory. Noctilucent clouds were being studied in greater detail for their own sake, and the major structure they revealed was sharply delineated into waveforms whose characteristics were those of gravity waves (see Fig. 1). The wavelike ionospheric disturbances were subjected to new, sophisticated means of detection, which revealed the local bulk motions and the temperature variations of the ionization itself, and found them to be in conformity with theory. These same disturbances, observed now to heights of 500 km, displayed new characteristics of propagation and attenuation that were appropriate to gravity waves at the levels in question. An artificial satellite, orbiting at similar heights, detected gross variations of atmospheric density which were readily explained as consequences of the same waves and were linked in due course to the occurrence of the ionospheric variations. New measurements of similar ilk appeared (and continue to appear) at frequent intervals in the literature—even to the point of embarrassment, on occasion, when exaggerated claims of confirmation were advanced. In sum, it may be said that not all of the upper atmospheric data originally attributed to gravity waves have been established as such, nor have any parts been convincingly rejected. There do remain areas of legitimate doubt. The greater portion has certainly been accepted and extended, however, and the overall picture is beyond dispute: gravity waves contribute an outstanding component to the dynamical system of the upper atmosphere⁴⁻⁷.

Does this component have its origins in whole or in part at much lower elevations, as Hines conjectured? The answer to this must vary somewhat, from one portion of the wave spectrum to another. In the case of the wavelike ionospheric disturbances, or at least their stronger members, there soon appeared to be a correlation with auroral and magnetic storms: the occurrence of strong waves was linked to sub-storm activity, and the waves themselves propagated equatorwards from the auroral zones. Electric currents, flowing at heights somewhat above 100 km in the auroral zones, came

to be recognized as the relevant sources. Because the waves are observed at greater elevations, their sources must indeed lie below the levels of observation—just as the downward progression of the rippled structure had suggested—but certainly not, in this case, in the lowest atmosphere.

Less intense wavelike disturbances, and the general spectrum that contributes the bulk of irregular gravity-wave winds and temperature fluctuations in the upper levels, have less certain origins. They may well be generated by the meteorological processes of the lowest atmosphere, but this remains unproven. The possibility of propagation from low altitudes to high was established unequivocally, if rather incidentally, by a nuclear detonation low in the atmosphere which launched one of the strongest ionospheric waves ever observed, but this hardly constituted comment on the ability of natural processes to provide observable amplitudes. The Californian data of the preceding decade served better in this respect: on further analysis they revealed a flux of gravity-wave energy upward from the troposphere at a rate that could account for typical irregular winds of the upper atmosphere, at least over a limited area for a limited time, and the upward transmission was favoured at the wave periods most required⁸. This is significant supportive evidence, but hardly conclusive. More recent efforts have been directed toward the correlation of individual sets of high-altitude data with individual low-altitude wave systems or meteorological conditions. These attempts have claimed only limited success, but certainly sufficient to keep current the view that meteorological sources are indeed major if not dominant contributors to the upper atmospheric spectrum.

Lower Atmospheric Observations

This view might be strengthened if we were able to say more about the waves that do occur low in the atmosphere; but our knowledge of these waves is severely limited, odd though this may seem. Eckart's tentative identification remains to be established as a general truth unless, retrospectively, one is prepared to admit its validity almost as a matter of definition. Even then, such an identification would carry little physical import unless the waves could be shown to be free of serious interaction with one another over much of their lifetime. The question is not one that can be answered by the normal meteorological networks of observ-



Fig. 1 Noctilucent clouds, at a height of 83 km, photographed by G. Witt⁴. The horizontal separation of principal crests is approximately 40 km, and the vertical amplitude of oscillation exceeds 1 km. For greatest visual effect, the photograph should be viewed upside-down.

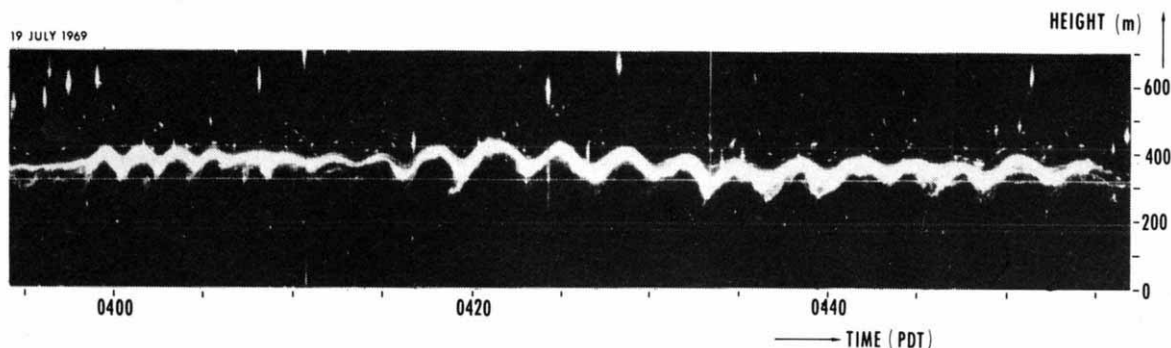


Fig. 2 Waves at a height of 300 to 400 m, detected by Gossard *et al.*¹¹ in clear air with highly sensitive radar. These may be Kelvin-Helmholtz waves, generated by local wind shears, but ancillary observations show them to be coupled to gravity waves of the more general type discussed in the text.

ing stations, for the grid size of these networks is too great and their data are not analysed on a sufficiently fine time scale. Special techniques of meteorological observation and analysis are required, and are only now coming to be applied^{9,10}.

The problem at these lower heights may well be one of profusion. If the fluctuating winds are indeed a manifestation of gravity waves, then in typical circumstances so many of these waves are superimposed that no single one may be recognized. Exceptions do occur when individual spectral components rise well above the general noise level; micro-barographic networks have revealed many such cases⁹. These sometimes occur in association with specific meteorological processes, notably with the passage of cold fronts and with the occurrence overhead of strong jet streams, but at other times their origins are more obscure. Sensitive electromagnetic radars, and their acoustic equivalents, reveal strong wave formations at sharp interfaces within the atmosphere, defined by sharp variations of wind, temperature, humidity or turbulence¹¹ (see Fig. 2). These radars have been supported with ancillary measurements of many sorts, by means of which more of the wave structure is revealed. The waves seem to be generated at the interfaces themselves in some cases, but at other times it seems that lesser waves originate elsewhere, propagate to the region of observation, and there trigger an incipient instability to produce more prominent effects. The number of instances in which gravity waves are revealed unambiguously must imply many more in which those waves have lesser amplitudes that are lost in the background noise; they support the idea that the waves do in fact constitute that noise. The noise itself is often described as "turbulence", and discussed on the basis of turbulence theory, but it is now evident that the more relevant theory may well be that appropriate to gravity waves.

Theoretical Approaches

There are several relatively distinct channels of theoretical endeavour. First, there is the question of local properties in the elementary waves, a question that had already been attacked and to some extent answered at the beginning of the 1960s. It was known, for example, that the oscillatory motion in internal gravity waves tends to be a shearing motion, in which neighbouring sheets of air parcels slide back and forth across one another, rather than a motion of approach and retreat as in sound waves; this was one of the properties that had led to the initial identification of upper atmospheric winds as gravity waves. And it was known that the compressional effects were correspondingly minimized, as Eckart had stressed. But what of the variations that would be induced in the ionization of the upper atmosphere, in the condensation of water vapour at lower levels, and in similar dependent parameters? Answers to

such questions often require investigation of complex processes¹², and have not yet been provided in full.

And what are the theoretical characteristics of propagation of the waves? The illusory nature of the vertical progression of ripples, as distinct from energy, was of course already known. Likewise, it was known that internal gravity waves can propagate their energy only over a restricted range of angles about the horizontal, and that a wave of given period tends to beam its energy at a particular angle of ascent or descent. (This theoretical prediction was confirmed, incidentally, by the ionospheric disturbance that was launched by the nuclear explosion already mentioned. It has also been confirmed, somewhat more elegantly, in a controlled laboratory experiment.) It was known that vertical variations of temperature or wind cause refraction of the waves, with a resultant bending of the ray path, and that they can in some circumstances cause reflexion. But it was not known in any detail how the actual variations of temperature and wind filter the real spectrum of gravity waves. Nor was it known how important might be the formation of "ducts" which, by reflecting energy upward and downward between specific levels in the atmosphere, might guide that energy to distant portions of the globe; nor what fraction of the guided energy might leak upward out of the duct to produce once again waves of exponentially increasing amplitude. It was known that the effects of viscosity and thermal conduction

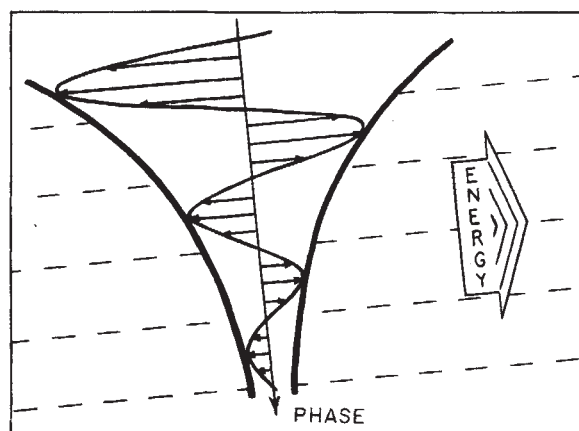


Fig. 3 Schematic representation of an elementary internal atmospheric gravity wave at one instant. Wind vectors amplify exponentially with height in a sinusoidal pattern. Vanishing winds (and extremes of temperature and density fluctuations) occur on inclined planes of constant phase, depicted as broken lines. These propagate with the sinusoidal pattern, as shown by the PHASE velocity vector. The region occupied by a system of such waves would propagate differently, however, in the direction of ENERGY flow.

increase with height, as the molecular mean free path increases, and that this ultimately limits the elementary exponential growth if other processes do not; but it was not known in any detail how these effects alter refraction, reflexion and ducting, nor what shock waves might become established if the exponential growth were not limited sufficiently.

Answers to many of these questions have now been found, and have been applied to observations in a few cases^{13,14}. The process of answering has led to new questions, as is hardly surprising. The foremost among these concern "critical levels" in the atmosphere, at which the background wind comes to match the horizontal speed of progression of a gravity wave. Such levels had already been recognized as having unique properties, in earlier studies of mountain waves and of shear-generated gravity waves, but they are seen now to have a more general role whose full extent is yet to be established.

The identification of likely wave sources, and the deduction of the associated wave spectra, constitute another area of theoretical concern. Mountain waves were of course already well known, but these waves were locked in position to their mountains and so could hardly contribute to the spectrum of travelling waves that was now called for. Unless, perhaps, the flow of wind over the mountains is variable (as indeed it is in practice), might not radiation of the waves then occur? Moving weather systems of all sorts, particularly frontal and storm systems, had to be suspect; but what is the mathematical description of the generation process? Certain instabilities of the general meteorological circulation and of planetary waves were recognized as generators of gravity waves; but with what characteristics, and what intensity? Which processes were likely to be of greatest importance, where, and in what season? Theory has not yet come to grips with these questions, though it has been successful with respect to more isolated and esoteric sources: nuclear explosions, major earthquakes, auroral electric currents, and even an eclipse of the Sun.

Energy and Turbulence

Granted the sources of gravity wave energy, what of the sinks? Viscosity and thermal conduction serve not only to alter wave propagation, but also to dissipate wave energy as heat. They are introduced as relevant processes in part by turbulence, which carries with it its own coefficients of "eddy" viscosity and conduction, but turbulence normally extends only to heights of 100 km or so. In the uppermost atmosphere molecular viscosity and conduction become more effective: molecules there travel considerable distances between successive collisions, and so can carry the organized energy and momentum of a wave system to places where it ought not be, thereby degrading the wave energy to heat and transferring the wave momentum to the background flow. At the same levels, the ionization imposes an additional dissipative mechanism: when it is pushed (through ion-neutral collisions) by the background neutral gas, it resists motion across lines of the Earth's magnetic field, and it transmits that resistance to the gas. Photon radiation may also play a part, the varying emissions from the hotter and colder regions of a gravity wave system being disruptive of the general flow of that system's energy. The relative importance of these processes has been fairly well established during the past decade, at least with respect to variability over the wave spectrum and with height, but problems of detail remain and must await observational developments. Some problems of principle persist, in areas of complex interaction. The shearing winds of gravity waves can generate their own turbulence, for example, and can thus contribute to their own destruction; this effect, along with others, is enhanced as the waves approach those special "critical levels" to which I have referred. These complex processes are now

understood only in the barest outline and not in detail.

The dissipation of gravity-wave energy leads to a heating of the atmosphere. If this heating is significant over a wide area, it can modify the general circulation of the atmosphere and hence alter various parameters which depend on that circulation. Present estimates suggest that the heating is at least comparable with that provided by solar radiation at ionospheric levels, and certainly exceeds solar input during the night and at high latitudes in winter. Changes of circulation at these elevations are unlikely to affect the meteorology of our own levels in significant degree, but they do have consequences for the distribution of ionization and hence for the part of the world's global communications that is carried out by short-wave radio propagation.

Similar consequences emerge from variations of turbulence low in the ionosphere, brought about by variations in the gravity waves that give the turbulence its birth. Turbulence helps to maintain the atmosphere in a chemically mixed state to heights of ~ 100 km, but with its cessation the heavier species, such as nitrogen molecules, tend to diminish their concentrations rapidly with further increase of height, while the lighter species, such as oxygen atoms, tend to diminish rather more slowly and so increase in relative concentration. The ionization profile depends on the relative concentrations, and so can be altered by variations of turbulence or by variations in more direct mixing processes that may be induced by large-amplitude gravity waves. Observational evidence indicates that these variations do occur, and theory would say they must, but the extent of their role remains at the moment a matter for speculation.

Gravity waves may be the primary generators of turbulence at lower levels as well. More particularly, they may be the principal cause of the "clear-air turbulence" that bedevils aircraft on occasion^{10,11,15}; or, in superposition, they may even be its very constituents. Prediction of the conditions under which such turbulence may rise to uncomfortable or even dangerous intensity is clearly a matter of some concern to all who use the airways, in spite of advances that have been made in the remote detection of true turbulence by on-board instruments. Such prediction may soon become reliable in the lee-wave region of mountains and in close association with weather fronts, but it lies well in the future for more sporadic occurrences.

Momentum

The greatest significance of all, perhaps, lies in the transfer of momentum by gravity waves¹⁶. Wherever the waves are created, they extract momentum; wherever they are destroyed they give it up. Internal waves propagating upward are notorious in this respect simply because their region of deposition will be a region of diminished gas density: an amount of momentum extracted from the lower atmosphere, which may be small by the standards that apply there, can be of tremendous import to the tenuous upper atmosphere. Indeed, the momentum that is carried into the ionospheric regions every few hours by gravity waves can be shown to exceed the momentum already there, at least if no allowance is made for the vectorial nature of momentum, which permits some cancellation when a summation is made over different azimuths of propagation. This leads to the suspicion that momentum deposition is more important than heat deposition in determining the circulation of the upper atmosphere, and hence in assessing the effect of gravity waves on ionospheric behaviour.

Low in the atmosphere, the momentum carried by gravity waves is far less than that carried by the general circulation and by its superimposed planetary waves. It would be rash, however, to conclude that the momentum of the gravity waves is of correspondingly little consequence. The gravity waves can transport their momentum much more rapidly than can the other systems: the flux of their momentum is

by no means small in comparison. Also, the gravity waves can transport this momentum in azimuths that are not available to the other systems, and they can have quite distinct regions of source and sink. Thus they can induce alterations in the more dominant systems, and these alterations may rise to major significance. By altering the background flow, they alter the characteristics of propagation and hence, in a feed-back process, the changes in that flow may damp out or amplify. There is evidence that this feed-back process is of considerable significance in the formation of the small scale instabilities that we classify as turbulence, and there is much room for speculation that they are important to the formation—or to the suppression—of larger scale instabilities such as typhoons or hurricanes. It is in areas such as these that their chief impact on man may in time be found.

Gravity waves may of course occur in atmospheres other than that of the Earth, and may well have been observed already in that of the Sun. Indeed, it is thought that these waves may be responsible for the maintenance of high temperatures observed in the solar corona, which are otherwise difficult to explain. The relevant mechanism would be the same as that already discussed with respect to the Earth's upper atmosphere: the deposition, and conversion to heat, of gravity-wave energy propagated upward from the denser regions beneath¹⁷.

Atmospheric Tides and Planetary Waves

Complementary to the study of gravity waves themselves, there has been a tremendous interlocking advance in the study of atmospheric tides and planetary waves during the past decade^{18,19}. Heating, rather than gravitational attraction, has been established as the dominant mechanism for the generation of solar tides, and has dispelled the problem of why those tides exceed the lunar atmospheric tides (in contrast to the case of oceanic tides, where the lunar component is the stronger). Likewise, a proper integration of rotational modes with gravity-wave modes in the 24 h solar tide has led to an explanation of that tide's weakness relative to the 12 h solar tide, in spite of the predominance of the 24 hour heating cycle. At longer periods, the upward propagation of planetary-wave energy has come under intensive study, drawing on and supporting in return the corresponding studies of gravity wave propagation. Statements made previously with respect to gravity waves, concerning the formation of turbulence and the deposition of heat and momentum, may be carried over to the internal tidal and planetary waves, occasionally with greater force of argument. A "quasi-biennial oscillation" in the mean flow, at low latitudes in the stratosphere, has been discovered and linked tentatively to a process of momentum transfer by internal waves. The relevant waves have periods of several days, and have characteristics that combine those of gravity and planetary waves at higher latitudes.

Complementing these atmospheric studies, and interacting with them to a considerable extent¹⁵, has been the study of oceanic dynamics²⁰. The formation of evanescent waves at internal interfaces and regions of strong shear, the propagation of internal waves through regions of continuous density gradient, and the creation of turbulence by both, constitute analogues of the atmospheric problems. These problems are relevant to the conditions that maintain the oceans of the world as a source of food. Direct interactions between the atmosphere and the seas occur, of course. Atmospheric storms whip up ocean waves in an irregular process that still defies adequate description, and is probably of little concern to our present discussion. But long fetches of wind are also known to create major water-wave systems, and to effect a transfer of momentum to the water that is important to the course of oceanic currents. The coupling mechanism from wind to water is still not understood in detail, but without a doubt it involves atmospheric gravity waves. These probably

link the water surface to a "critical layer" in the atmosphere, permitting an efficient conversion of energy and momentum from above to below.

The reverse process, from water waves to air, must also occur, but has scarcely been studied. One recent article²¹, launching us firmly into this field, concludes that the atmospheric lunar tide is generated predominantly by the oceanic tide—that its source is to be found mathematically as a variation in the lower boundary of the atmosphere, rather than as a lunar gravitational attraction distributed throughout the atmosphere. We may extend such considerations by speculation, as yet unconfirmed by analysis, concerning the "tidal waves" (tsunamis) of ill repute. Tsunamis have their origins in major earthquakes beneath the ocean floor or at its verge. A tsunami rises to rampaging amplitudes only in shallow waters, typically at the coasts themselves, where its energy must be carried by relatively small masses of water. In the open ocean, a tsunami is very tame indeed, producing, perhaps, a few metres' rise or fall of water, and that spread over a horizontal peak-to-trough distance of many km. Tsunamis are therefore virtually undetectable in the open ocean, and the prediction of their appearance on shore is most difficult. But a tsunami must displace the atmosphere as it propagates and the displaced atmosphere must respond by generating a gravity wave. The parameters are such that these waves will be of the internal type, and so will grow exponentially with height. A rise of a few metres at the surface of the water might well amplify to a few km at ionospheric heights, and that sort of amplitude could hardly escape detection if it were sought. We arrive, then, at this speculative question: If we wish to keep track of the progress of a tsunami, and so predict with some assurance the onslaught of its destructive force, might we not serve our interests best by keeping watch on the ionosphere?

Nor is speculation about gravity waves limited to the physical sciences alone. One example that lies beyond their scope concerns the migration of many species of birds, which proceeds unhampered by leaden skies or fog-shrouded ground or by magnets or other devices attached to the birds in attempts to find a clue. In desperation, perhaps, it has now been asked²² whether there might be patterns of atmospheric gravity waves (induced by underlying terrain, perhaps, or by typical jet-stream configurations) which birds might be able to identify and employ as a route map, in their travels from one feeding ground to another.

¹ Bjerknes, V., Bjerknes, J., Solberg, H., and Bergeron, T., *Physikalische Hydrodynamik mit Anwendung auf die Dynamische Meteorologie* (Springer, Berlin, 1933).

² Eckart, C., *Hydrodynamics of Oceans and Atmospheres* (Pergamon, 1960).

³ Hines, C. O., *Canad. J. Phys.*, **38**, 1441 (1960).

⁴ Witt, G., *Tellus*, **14**, 1 (1962).

⁵ Revah, I., *Ann. Géophys.*, **25**, 1 (1969).

⁶ Testud, J., and Vasseur, G., *Ann. Géophys.*, **25**, 525 (1969).

⁷ Dyson, P. L., Newton, G. P., and Brace, L. H., *J. Geophys. Res.*, **75**, 3200 (1970).

⁸ Gossard, E. E., *J. Geophys. Res.*, **67**, 745 (1962).

⁹ Herron, T. J., Tolstoy, L., and Kraft, D. W., *J. Geophys. Res.*, **74**, 1321 (1969).

¹⁰ Axford, D. N., *Quart. J. Roy. Met. Soc.*, **97**, 313 (1971).

¹¹ Gossard, E. E., Richter, J. H., and Atlas, D., *J. Geophys. Res.*, **75**, 3523 (1970).

¹² Hooke, W. H., *J. Atmos. Terr. Phys.*, **30**, 795 (1968).

¹³ Friedman, J. P., *J. Geophys. Res.*, **71**, 1033 (1966).

¹⁴ Cowling, D. H., Webb, H. D., and Yeh, K. C., *J. Geophys. Res.*, **76**, 213 (1971).

¹⁵ *Proc. Colloquium on Spectra of Meteorological Variables*, *Radio Sci.*, **4**, 1099 (1969).

¹⁶ Jones, W. J., and Houghton, D. D., *J. Atmos. Sci.*, **28**, 604 (1971).

¹⁷ Whitaker, W. A., *Astrophys. J.*, **137**, 914 (1963).

¹⁸ Chapman, S., and Lindzen, R. S., *Atmospheric Tides* (D. Reidel Press, Dordrecht, Holland, 1970).

¹⁹ Dickinson, R. E., *J. Atmos. Sci.*, **26**, 73 (1969).

²⁰ Phillips, O. M., *The Dynamics of the Upper Ocean* (Cambridge University Press, 1966).

²¹ Hollingsworth, A., *J. Atmos. Sci.*, **28**, 1021 (1971).

²² Griffin, D. R., *Quart. Rev. Biol.*, **44**, 255 (1969).

The Faeroe–Iceland–Greenland Aseismic Ridge and the Western Boundary Undercurrent

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The Miocene increase of bottom currents in the western North Atlantic is linked to subsidence, by thermal contraction of the cooling lithosphere, of the sills forming the aseismic ridge east and west of Iceland.

STUDIES of the circulation pattern of the North Atlantic show that cold, dense water forms and sinks in the Norwegian Sea, north of Iceland, and spills south over the Iceland–Faeroe–Greenland aseismic ridge^{1,2}. Some turns north into the southern Labrador Basin, but all eventually swings south around the Grand Banks and into the western Atlantic, where it is linked with the formation of sediment drifts such as the Blake–Bahama Outer Ridge^{3,4}.

When did this circulation pattern originate? Recent JOIDES drilling on the Blake–Bahama Outer Ridge shows that the sediment drift is of Miocene (25 to 11 m.y. BP) and younger age^{5,6}, and I assume this is the time of origin of a vigorous Western Boundary Undercurrent south of the Grand Banks. Farther north in the Atlantic, in the southern Labrador Sea, currents seem to have begun somewhat earlier, during the Oligocene or Late Eocene^{7,8}, becoming steadily more pronounced with time thereafter⁸. W. Ruddiman (personal communication) finds two periods of rapid bottom-current type sedimentation on the eastern flanks of Reykjanes Ridge—45 to 35 m.y. BP and 18 to present. The latter pulse may correspond with the Miocene^{5,6} beginning of rapid sedimentation on the Blake–Bahama Outer Ridge. Although the major sediment drifts in the north-east Atlantic have been charted by ship^{9–11}, deep drilling control for the timing of events is still inadequate⁷. In summary, the available evidence suggests that active bottom currents, derived from the Norwegian Sea, began to invade the Atlantic south of Iceland during the Miocene, although lesser activity may have begun as early as late Eocene. The overall trend is one of steadily increasing current activity.

What events could have caused the bottom water to begin or at least to become vigorous in the Miocene, say 20 m.y. BP? The beginning of glaciation was much more recent, about 3 m.y. BP⁷, whereas the opening of the rift between Greenland and Scandinavia occurred about 60 m.y. BP (O. E. Avery and P. R. Vogt, personal communication). It is reasonable that the dense water was formed in the Arctic basin during rela-

tively warmer pre-Pleistocene times; the time when a deep water connexion first formed between the Arctic Ocean and Greenland seas may then be important. It has been inferred from seafloor spreading studies that Greenland moved north-west away from Scandinavia from 60 to 40 m.y. BP, when motion became more nearly east–west^{12,13}. The latter movement has tended to widen the sea between Spitsbergen and Greenland; thus, any bottom water contributions from the Arctic Ocean may not have had good access to the North Atlantic until 40 m.y. BP. Although this “event” might explain the first beginnings of bottom currents in the late Eocene–early Oligocene^{8–11}, it still predates the Miocene buildup noted above⁵.

Role of the Faeroe–Iceland–Greenland Aseismic Ridge

These events may have influenced bottom currents, but the timing problem suggests there must be another factor. I suggest that this factor is the Faeroe–Iceland–Greenland aseismic ridge (Fig. 1). Approximately a third of this ridge is above sea level today, in the form of Iceland, and the submerged parts are not deeper than approximately 0.7 km west of Iceland and 0.5 km to the east. Thus the ridge now forms a spillway over which Norwegian sea subsurface water enters the North Atlantic. Could this sill have been subaerial, like present Iceland, until approximately middle Tertiary times? Continued sinking of oceanic crust, caused partly or wholly by thermal contraction of the lithosphere after it forms at the spreading axis, seems to affect all oceanic regions and proceeds with a time constant of about 50 m.y.^{14–16}. There is no reason why the Iceland area should not have undergone such subsidence.

Deep drilling on the submerged limbs is necessary to prove the hypothesis that they were once at sea level, but, even without such data a strong case, as well as some idea of the time of sinking, can be derived from simple considerations. First, at least the eastern limb of the ridge, between Iceland and the Faeroe Islands, has a relatively broad flat crest¹⁷ suggestive of a large guyot. This flatness is not the result of marine sediments, which are at most a few hundred metres thick^{17,18}. The active overflow currents surely help to sweep any new pelagic sediment off the crest.

Consider now the process of subsidence. The “negative hypothesis” is that the submerged crust was never above sea level. Assuming it was just at sea level it follows from the exponential subsidence, of the form $E_0 e^{-t/\tau}$, where E_0 is an initial topographic anomaly of roughly 4 km, and t is in m.y.

BP, that crust dating from 30 to 60 m.y. BP should now be at -1.8 to -2.8 km. The observed values are -0.3 to -0.45 km on the eastern limb and a maximum of -0.64 km on the western limb. This shows either that the lithosphere containing the aseismic ridge is contracting much more slowly

merged portion near the Faeroes²⁰). This greater thickness of comparatively low conductivity crust would slow thermal subsidence somewhat, but because this crust is still only a small fraction of lithospheric thickness, it is unlikely that the effect would greatly increase the time constant of about 50

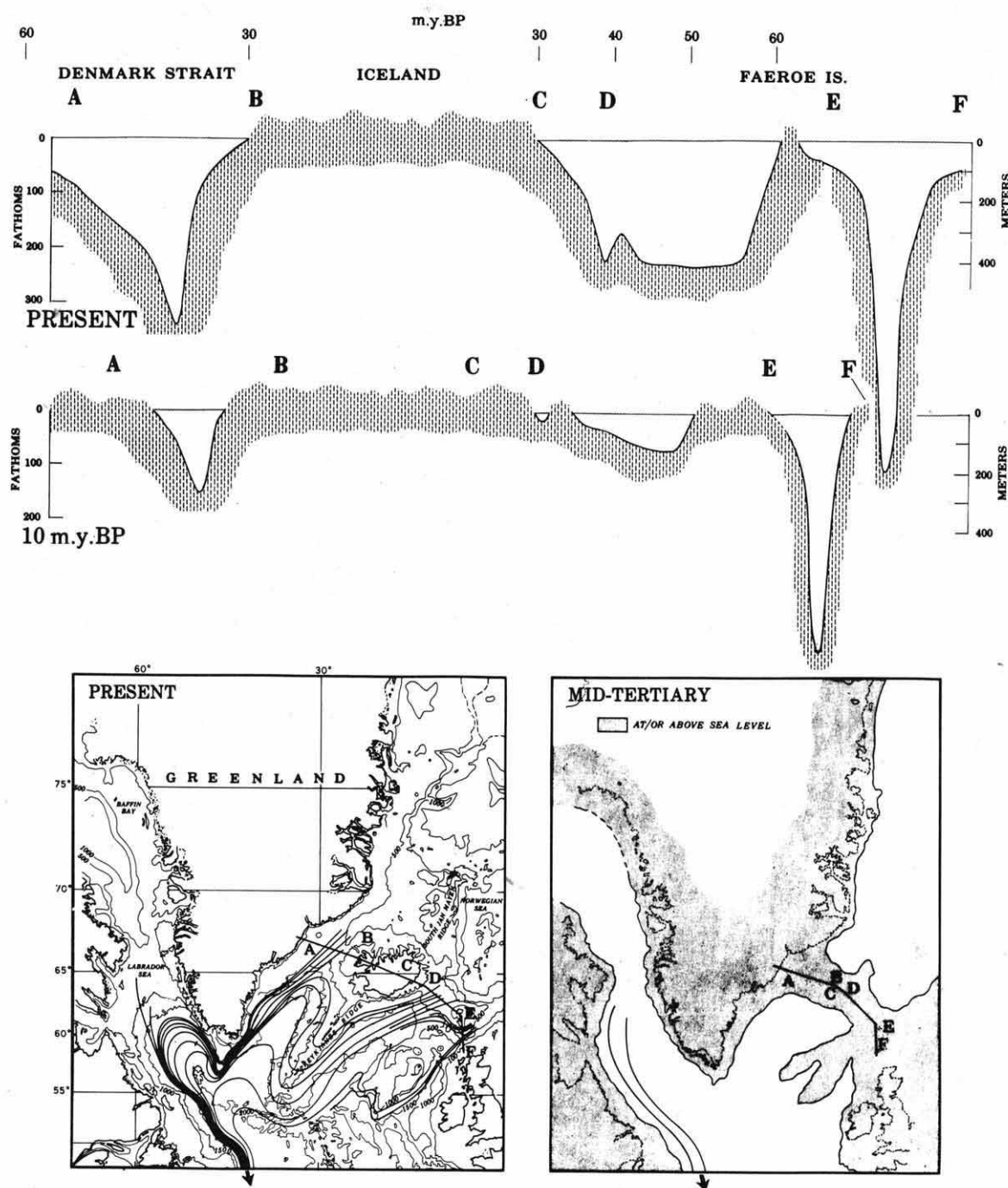


Fig. 1 Present and 10 m.y. BP depth profile along crest of Faeroe-Iceland-Greenland aseismic ridge. 10 m.y. BP profile was computed by applying 50 m.y. subsidence time constant and an initial topographic anomaly of 4 km to submerged portions of sill. Below, present and Mid-Tertiary palaeogeography, showing proposed subaerial or very shallow water. Faeroe channel crust, probably continental, was also assumed to subside with 50 m.y. time constant¹⁴.

than typical lithosphere, or that the top of the ridge was initially exposed well above sea level, its top having been removed by erosion. True, the aseismic ridge has a basaltic layer thicker than the 5 km typical for oceanic crust (about 8 to 15 km on Iceland¹⁹ and 15 to 20 km on the older sub-

m.y. (refs. 14-15). Additionally, the older aseismic ridge represents an excess basalt accumulation not much wider than the lithosphere is thick. Thus the error caused by the anomalous low conductivity of the excess basalts would decay at a much faster rate than the 50 m.y. time constant associated with the

mid-oceanic ridge, which is a two dimensional structure because this ridge is much longer than the lithosphere is thick. It is much more probable that the present -0.5 km level of subsidence on the submerged limbs of the aseismic ridge represents only the subsidence that has occurred since the limbs first dropped below sea level—a time perhaps much later than the crust was formed. The earlier this event occurred, the older the crust.

There are several ways to estimate the time of initial subsidence. The east-west width of present day Iceland is probably greater than in the past²¹, but by assuming the present day width is typical we may arrive at an approximate value for the time of subsidence. Iceland is now 500 km wide or 750 km if shallow shelves are included. The oldest subaerial crust is at least 20 m.y. old; from northward extrapolation of magnetic anomalies south of Iceland (O. E. Avery and P. R. Vogt, personal communication) the crust under the oldest edges of the Iceland shelf must be nearly 30 m.y. old. Hence, Icelandic crust now takes ~ 20 m.y. to disappear below sea level and ~ 30 m.y. to drop below shelf depths. Because seafloor spreading began 60 m.y. ago in this area, it follows that a proto-Iceland could have formed a continuous land bridge from Greenland to the Faeroes until 40 m.y. BP, with only shallow straits until 30 m.y. BP. Since then the sill has deepened and the width of open water widened. Although these figures are rough, they suggest that the late-Eocene beginning of bottom currents south of Iceland may reflect the first open water between Greenland and the Faeroes, and that the Miocene increase in current activity reflects the point at which sill depths were great enough to admit subsurface water from the Norwegian Sea. The following simple process would make the Miocene a recognizable, that is, abrupt, event: the early, weak currents spilling over the sill allowed proto-Iceland to form shallow sediment-floored shelves that continued to hold back deeper water even though the basement had by now subsided to several hundred metres. As the shelves widened, their distal parts began to deepen slightly because of decreasing sediment input. At a certain threshold sill depth and width, a feedback process was initiated; currents became slightly swifter, eroding more of the shelf sediments, thus deepening the channels (one on each side of Iceland), which in turn admitted still denser water and further increased current strength, and so on. The Faeroe channel probably deepened abruptly in a similar manner. Much of the sediment was stripped off rapidly, and relatively large volumes of Norwegian Sea deep water now flowed over the two deepened sills to form the Western Boundary Undercurrent. A gradual climatic deterioration, strengthening current flow over the early shallow sill, would cause a similar feedback effect, which is implied by data from JOIDES drilling on the Blake-Bahama Outer Ridge¹⁹ and also inferred in the north-East Atlantic (W. F. Ruddiman, personal communication).

It is interesting that only 20 or 30 m.y. are required for the combination of erosion and thermal contraction to lower Icelandic crust to sea level, because the figure for the initially uplifted edges of a continental rift is about 50 m.y.^{14,15}. Because the thermal anomaly causing the initial expansion is shallower in the oceanic case, it seems that erosion of several km of axial crust on Iceland, plus deep fissuring and ground water convection, could speed up the initial stages of heat removal and thermal contraction, thus reducing the time constant below 50 m.y. This effect, however, must first overcome the relatively low conductivity of the crust, which would tend to increase the time constant.

The problem of sill subsidence can be approached another way which leads to a slightly different timing. I now ignore modern Iceland and look only at present sill depth along the submerged portion of the aseismic ridge. The age of each point on the ridge may be estimated by extrapolating magnetic anomaly isochrons from the ocean basin to the south (O. E. Avery and P. R. Vogt, personal communication). If a 50 m.y. time constant describes subsidence once the crust is below sea level, a longitudinal depth profile (east to west) can be calcu-

lated for each point in time. As total cross-sectional area and maximum sill depth are reduced, going backward in time, we can imagine turning off the "valve" that controls the passage of Norwegian Sea water into the North Atlantic.

In Fig. 1 the present profile has been recomputed to 10 m.y. BP, assuming that once sea level is reached, the crust subsides as typical ocean floor. This profile shows very little open water; at 20 m.y. BP there would be only a fraction of the Faeroe channel. Even if we are generous and assume 0.5 km marine sediments on the sill (several hundred metres sediment have been detected on the western sill, east of Iceland^{11,18}), there was essentially no open water before the Miocene unless sill subsidence differed grossly from that of normal oceanic crust. The Faeroe channel, east of the Faeroe Islands, is somewhat deeper than the sill, but it would have undergone similar subsidence¹⁴⁻¹⁶. The subsidence calculated (Fig. 1) agrees well with the 18 to 10 m.y. BP "pulse" of bottom current sedimentation south of Iceland (W. F. Ruddiman, personal communication), the Miocene beginning of the Blake-Bahama Outer Ridge^{5,6}, and the gradual intensification of current activity with time⁸, all of which I attribute to gradual deepening and widening of the sill, allowing progressively more and deeper, denser water to spill over the sill. While the deep currents were intensifying this way, so also did the south-flowing East Greenland current and the north-flowing waters of the North Atlantic drift.

In summary, although the assumption of a steady-state Iceland leads to a 40 m.y. age for sill opening, and although the 50 m.y. subsidence time constant leads to a 20 m.y. age, the approximations involved make such disagreement understandable. The difference suggests that the initial thermal anomaly was at relatively shallow depths in the lithosphere; hence, initial uplift, erosion, and groundwater circulation could remove some of the thermal anomaly, leaving the remainder to decay with a somewhat greater time constant than 50 m.y. I conclude that the sill was essentially closed until Middle Tertiary times; this explains the absence of strong bottom currents until the middle Tertiary. A consequence of this hypothesis is that a land bridge existed between Europe and Greenland until the middle Tertiary, coeval with a Spitsbergen-Greenland land bridge postulated from seafloor spreading studies by Talwani and Eldholm¹².

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- ¹ Worthington, L. V., and Volkmann, G. H., *Deep-Sea Res.*, **12**, 667 (1965).
- ² Swallow, J., and Worthington, L., *Deep-Sea Res.*, **16**, 77 (1969).
- ³ Heezen, B. C., Hollister, C. D., and Ruddiman, W. F., *Science*, **152**, 502 (1966).
- ⁴ Schneider, E. D., Fox, P. J., Hollister, C. D., Needham, H. D., and Heezen, B. C., *Earth Planet. Sci. Lett.*, **2**, 351 (1967).
- ⁵ Ewing, J. I., *Geol. Soc. Amer. (Abstract)*, **7**, 560 (1971).
- ⁶ Scientific Staff, *Geotimes*, **15**, 14 (1970).
- ⁷ Scientific Staff, *Geotimes*, **15**, 10 (1970).
- ⁸ Le Pichon, X., Hyndman, R. D., and Pautot, G., *J. Geophys. Res.*, **76**, 4724 (1971).
- ⁹ Johnson, G. L., and Schneider, E. D., *Earth Planet. Sci. Lett.*, **6**, 416 (1969).
- ¹⁰ Johnson, G. L., Vogt, P. R., and Schneider, E. D., *Deutsch. Hydrogr. Zeit.*, **24**, 4 (1971).
- ¹¹ Jones, E. J. W., Ewing, J. I., and Eitrem, S. L., *J. Geophys. Res.*, **75**, 1655 (1970).
- ¹² Talwani, M., and Eldholm, O., *Geol. Soc. Amer. (Abstract)*, **7**, 728 (1971).
- ¹³ Vogt, P. R., Avery, O. E., Anderson, C. N., and Bracey, D. R., *Tectonophysics*, **8**, 285 (1969).
- ¹⁴ Sleep, N. H., *Trans. AGU*, **51**, 429 (1970).
- ¹⁵ Vogt, P. R., and Ostenso, N. A., *Nature*, **215**, 810 (1967).
- ¹⁶ Sclater, J. G., Anderson, R. N., and Bell, M. L., *J. Geophys. Res.*, **76**, 7888 (1971).
- ¹⁷ Fleischer, U., *Mar. Geophys. Res.*, **11**, 111 (1970).
- ¹⁸ Johnson, G. L., thesis, Univ. Copenhagen (1971).
- ¹⁹ Bott, M., Ingles, A., and Stacey, A., *Trans. AGU*, **52**, 352 (1971).
- ²⁰ Palmason, G., Science Institute, University of Iceland and National Energy Authority, Reykjavik, Iceland (1970).
- ²¹ Vogt, P. R., *Earth Planet. Sci. Lett.*, **13**, 153 (1971).

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The passage of lithospheric plates over thermal plumes or hotspots in the mantle is discussed with respect to the history of two igneous chains in the European plate.

Along the oceanic rifts (ridges) which propagate between plumes, on the other hand, aesthenosphere rises and partial melting occurs at much shallower depth, so that the magmas are characteristically tholeiitic. The chemical differences between ocean ridge (*per se*) or abyssal basalts and the basalts and related differentiates of the oceanic island "plumes" have been noted elsewhere^{9,11}.

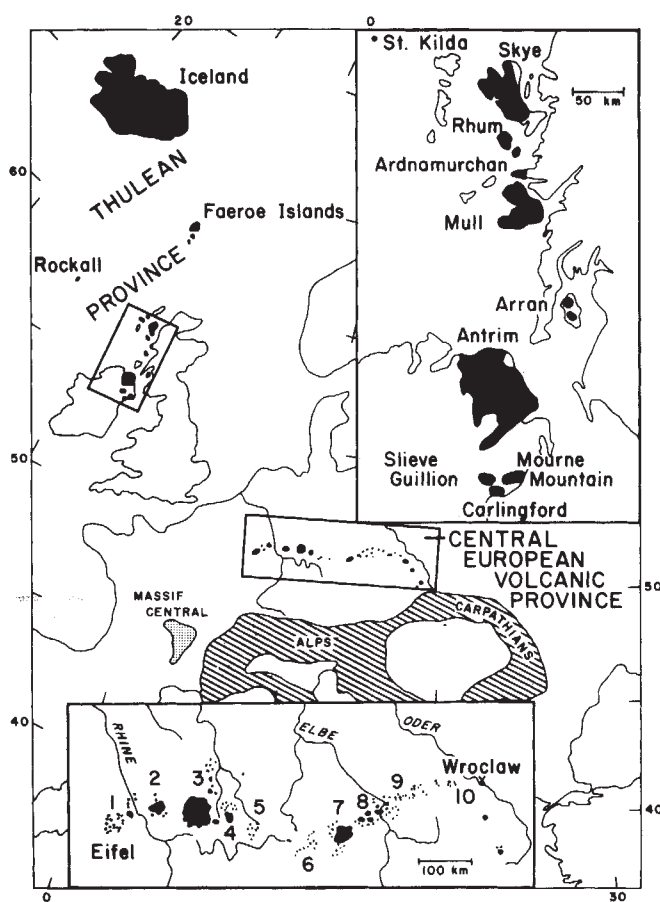


Fig. 1 Geographic map showing location of Thulean and Central European volcanic provinces, and the principal centres of which they are composed. 1, Eifel, Eifel Siebengebirge; 2, Westerwald; 3, Vogelsberg; 4, Knüllgebirge; 5, Rhon; 6, Reichsfurst; 7, Dupperrauergebirge; 8, Bohemian Mittelgebirge; 9, Lausitz; 10, Bober-Katzbach.

Plumes and Cratonic Activity

Dunham¹² has suggested that the magma source now beneath Iceland earlier produced the Tertiary igneous centres of Scotland and other members of the Thulean Province. Migration from this stationary centre is attributed to seafloor spreading. If Morgan's model is correct, plumes tend to rupture and drive crystal plates, and normal faulting or rifting is commonly associated with the emplacement of alkalic igneous complexes. The general hypothesis advanced here, however, is that mantle plumes are primarily responsible for all cratonic igneous activity which is or was clearly independent of plate boundaries.

The passage of a lithospheric plate over mantle plumes should leave surface scars in the form of igneous activity. If the plumes are stationary within the mantle (aesthenosphere), the pattern of these scars, on oceanic or continental crust,

oceanic and continental crust; the other (the Eifel plume) is entirely confined within the continent (Fig. 1).

The principal volcanic or igneous components of the two plume provinces are shown in Fig. 1. A summary of the rock types found and the available radiometric and stratigraphic age data are listed in Table 1¹³⁻²³ and Table 2²⁴⁻³⁴.

In the Thulean Province¹³⁻²³, the age data suggest a general increase in age from Iceland to the Faeroe Islands and Northern Ireland. If this is considered to be a single scar-trace, however, the distribution pattern and age data reveal distinct segments. These may represent different orientations and velocities for the motion of plate relative to plume. Interpretation in terms of the plume model is by no means simple, however, and for clarity the history of the Thulean Province will be discussed with reference to three geographic segments: Iceland-Faeroes; Skye-Mourne Mountains; Faeroes-Rockall-Skye.

Table 1

Igneous centre	Form of activity	Age (m.y.)	Reference	Petrology
Iceland ¹³		0-16.3	14	
Faeroes ¹⁵	Flows	55	16	Olivine basalts, tholeiite
Rockall	Intrusive	49, 60	17	Aegirine granite
St Kilda	Central complex	36 ± 6	17	Basic
Skye	Tuffs, fissure eruption, central plutonic complexes	54 ± 3	19	Olivine basalts, mangerites, trachytes, alkalic granites, gabbros and differentiates Olivine basalts, differentiated ultrabasics
Rhum ¹²	Lavas, layered complex in volcanic throat			
Ardnamurchan	Three volcanic centres, stocks, ring dykes	55 ± 6	20	Gabbro, eucrite, granophyre
Mull ¹⁸	Calderas, sheets ring dykes, explosive vents (doming)	60 ± 12	21	Granophyres, olivine, gabbros, eucrite
Arran	Granite stock, central ring complex	60 ± 6	20	Granite, gabbro, ring dykes
Antrim Plateau	Lavas	74	18	Olivine basalts, tholeiites
Mourne Mountain	Ring dykes	75 ± 7	22	Granites, felsites
Slieve Gullion ²³	Ring dykes			
Carlingford				

Table 2

Igneous centre	Form of activity	Age	Reference	Petrology
Eifel ^{24,25}	Strato volcanics	10,000 yr		
Eifel-Siebengebirge ^{24,25}	Tuffs, flows	Miocene, 18-26 m.y.	30	Trachyte, andesite, basalt
Westerwald ²⁵	Tuffs, lavas	Pliocene		Trachyte, basalt
Vogelsberg ^{24,26,27}	Lavas (doming)	Tortonian, Sarmatian, Pliocene		Phonolites, basalts
Knüllgebirge ²⁴	Lavas	Miocene		Trachy-dolerites, feldspathic basalts
Rhön ²⁴	Lavas (doming)	Tortonian		Basalts, phonolite
Reichsforst, Oberpfalz ^{24,28}	Cones, flows	Miocene, 18-23 m.y.	30	Nepheline and melilite basalt
Duppauergebirge ^{25,29}	Tuffs, flows	Oligocene, Miocene		Nepheline basalt
N-Bohemian volcanics ²⁵	Tuffs, flows, laccoliths	Oligocene		Basalts, phonolites, essexite
Lausitz ^{24,30-32}		20-32 m.y.	30	Trachytes
Bober-Katzbach ^{25,33-35}	Flows	29-34 m.y.	34, 35	Basalt

would be a record of the absolute motion of the plate relative to the aesthenosphere.

Therefore if cratonic igneous centres are plume scars, they should demonstrate a temporal sequence, and a systematic geometry. Furthermore if polar wander curves are the result of lithospheric plate motion only, and the Earth's magnetic field is and has been a centred, axially symmetric dipole field, then the magnetic polar wander curve for a particular plate should likewise be compatible with its plume trace. If only the last test is not met, then either the assumptions implicit in it are invalid or true polar wander has occurred.

Here we attempt such an appraisal by reference to the history of two partly contemporaneous igneous chains in the European plate which are inferred to be the result of plume activity. One of these (the Thulean plume) traverses both

The oldest rocks on Iceland are found at the eastern (12.5 m.y. and western (16.0 m.y.) edges of the island¹⁴. Ages decrease toward the active rift zone¹³.

The Wyville-Thompson ridge extends from Iceland to the Faeroes. Basalt has been dredged from this ridge, but no age data have been reported. The Faeroe Islands represent a high-lying part of the Wyville-Thompson ridge composed predominantly of quartz tholeiite flood basalts¹⁵. No substantially alkalic rocks have been described here. The age of the volcanic activity as given by radiometric age determination¹⁶ is between 50 and 60 m.y. (average 54 m.y.). The apparent velocity of plate-plume motion is 1.3 cm yr⁻¹ (Fig. 2).

From Skye to the Mourne Mountains the ages of igneous activity increased from about 54 m.y. (Skye) to 75 m.y. in the Mourne Mountains²² 350 km away. The volcanic centres

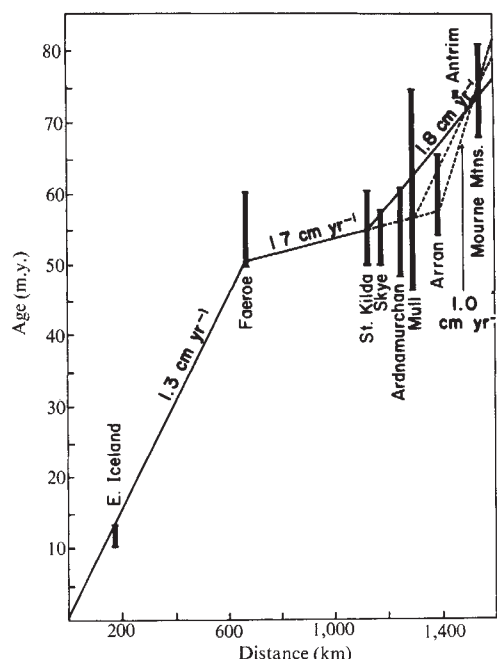


Fig. 2 A distance/time plot for the Thulean province showing contrasting rates for the three segments: Iceland-Faeroes, Faeroes-Skye, Skye-Mourne Mts. The rapid Faeroes-Skye segment could be extended back to Arran; in this case the Arran-Mourne Mountains segment would require a rate of 1.0 cm yr^{-1} . Such a choice is not critical for the arguments presented.

include some of the classic central complexes in the annals of igneous petrology. Rocks representing a spectrum of magma types and associated differentiates occur, but alkalic varieties are well represented (Table 1). The apparent plate velocity is between 1.0 and 1.8 cm yr^{-1} (Fig. 2), but because the trace is roughly north-south, the rotation pole is quite different from that associated with the Iceland-Faeroe segment.

We have not found a satisfactory explanation for the plate and plume relation during the formation of the Faeroes-Skye segment. The igneous activity responsible for Skye, the Faeroes, for Rockall and St Kilda is all essentially contemporaneous, around 55 m.y. ago^{19,21}, and a very rapid (about

15 to 20 cm yr^{-1}) southward movement of the plate is demanded (Fig. 2). But the principal opening of the north-east Atlantic is thought to have started about this time^{36,37}, and may be a cause of the complexity.

The Faeroes are located at the northern end of the Rockall Plateau. There are differing views on how this continental fragment became separated from Europe: Le Pichon *et al.*³⁶ suggest that it is the result of a once active NE-SW spreading ridge with its axis in the Rockall Trough, but Laughton³⁷ considers the Rockall Trough to be a NE-SW trending transform fault. In either case, however, if the separation of Rockall from Europe occurred after the plume had produced the Faeroes, the anomalously high plate velocity inferred from the Faeroes-Skye segment would in part be explained.

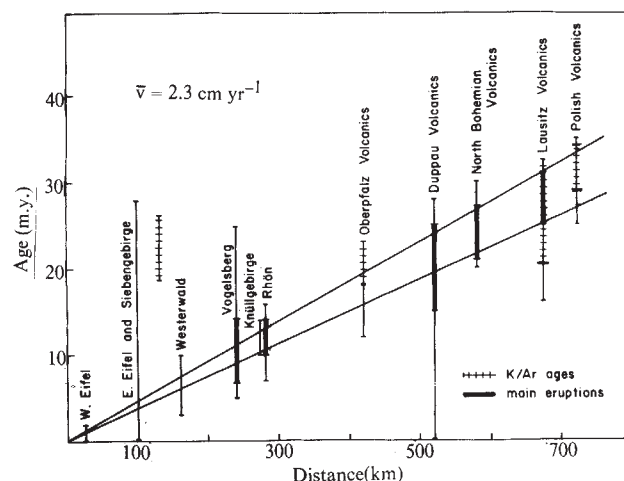


Fig. 3 Distance/time plot for the Central European volcanic province. The early initiation of volcanism in the E. Eifel-Siebengebirge-Westerwald area is tentatively attributed to the prior existence of the Rhine graben, which provided an easier ascent route for the magmas.

The volcanic province of Central Europe^{24,34,35} (the Eifel Plume) comprises a volcanic chain, over 700 km long, which extends from the Eifel Mountains in the west across central Germany and Czechoslovakia to upper Silesia in Poland (Fig. 1). the available data on age and petrological character

Table 3

Rotation pole	Rotation angle	Site	Reference	Age (m.y.)	Unrotated pole		Rotated pole	
					Latitude	Longitude	Latitude	Longitude
a 72N, 10E	8.2 c c=clockwise	Upper T, mean	39	20	83N	159W	83N	173E
			40	20	83N	143E	84N	172W
			39	20	83N	137E	81N	121E
(a) b 4.5N, 116W	a+5.5 ac ac=anti-clockwise	Lower T, mean	39	60	77N	150E	66N	123E
			40	60	76N	150E	66N	123E
			39	65	78N	153E	67N	125E
a 72N 10E	6.1 c	British Tertiary (Igneous)	41	65	77N	171E	67N	135E
			42	10	86N	66E	84N	72E
			43	6	68N	132E	67N	128E
			43	11	86N	168E	85N	147E
			44	12	83N	163W	83N	177E
			45	26	72N	137W	73N	160W
			46	28	75N	123E	71N	108E
			41	54	77N	161E	72N	122E
					02S	94W	4.5N	116W
					74N	157E	65N	127E
(a) b 4.5N 116W	a+4.5 ac	Skye	40	55	68.5N	151E	58N	125E
			40	55	69N	165E	59N	135E
			40	60	82N	69W	85N	162E
			40	60	72N	133E	61N	113E
			40	60	78N	149E	67N	123E
			40	60	78N	145E	66N	122E
			40	74	76N	138E	64N	118E
			47		70N	163E	69N	134E
a 72N 10E	a+5.2	Rhum	40	55	69N	165E	59N	135E
			40	60	82N	69W	85N	162E
			40	60	72N	133E	61N	113E
a 72N 10E	a+6.3	Mull { lavas intrusives	40	60	78N	149E	67N	123E
			40	74	78N	145E	66N	122E
			40	74	76N	138E	64N	118E
a 72N 10E	a+7.0	Arran	40	55	69N	165E	59N	135E
			40	60	82N	69W	85N	162E
			40	60	72N	133E	61N	113E
a 72N 10E	a+7.0	Antrim igneous non-igneous lavas	40	55	69N	165E	59N	135E
			40	60	82N	69W	85N	162E
			40	60	72N	133E	61N	113E

are given in Table 2 and Fig. 3. Igneous activity at individual centres has apparently persisted for up to 25 m.y., which suggests more or less contemporaneous activity throughout the length of the chain. If, however, only the period of most abundant and intense igneous activity at individual centres is considered, a consistent temporal sequence is evident (Fig. 3). The implied plate motion has a velocity of about 2.3 cm yr^{-1} .

Contemporaneous igneous activity over such a wide area can be regarded as evidence against the plume model; however, if these data are interpreted in this way, it requires that minor igneous activity can occur up to 600 km away from the plume site.

Comparison of Thulean and Eifel Plume Traces

The history of the Eifel plume can be traced back only about 35 m.y. In the Thulean province this interval is "represented" by a segment of the Wyville-Thompson ridge extending from Iceland about 400 km toward the Faeroes. From these two segments a rotation pole can be derived at 10° E , 72° N , that simulates well both the geometry of these two contemporaneous segments, and their apparent plate motion velocity (Thulean, 1.9 cm yr^{-1} ; Eifel, 2.3 cm yr^{-1} , see Fig. 4).

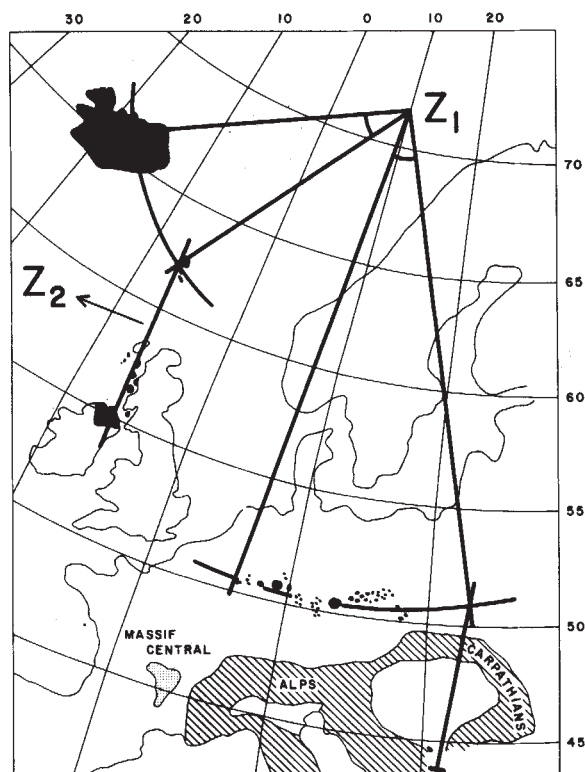


Fig. 4 Rotation pole (10° E , 72° N) and small circle arcs for Iceland-Faeroes segment of Thulean province and for the Central European province.

Using this rotation pole, the Eifel equivalent of the remaining Iceland-Faeroes segment can be predicted (Fig. 4). Although the exposed terrain here, however, consists of Mesozoic sediments³⁸, no evidence of an eastward extension of the volcanic chain can be found; it remains uncertain whether the Eifel plume was "born" only about 35 m.y. ago, or whether its earlier extensions are obscured by younger deposits or deformation (as in the Carpathians).

The Faeroes-Skye-Mourne Mountains segment of the Thulean plume scar extends almost north-south. Clearly a different rotation pole, located perpendicular to this trend, on

either side, and approaching 90° distant, must be invoked. The pole we favour is located at 4.5° N , 116° W (Fig. 4).

There appear to be no older igneous centres south of the Mourne Mountain, Slieve Gullion, Carlingford group (about 75 m.y.²²). Whether the Thulean plume was born only then, or before the European plate began to move in a direction other than due south, the plume scars being elsewhere, remains unclear.

Comparison of Plume Traces with Magnetic Polar Wander Curves

If we assume that plume traces are due to lithospheric plate motion only, that plumes are fixed in the mantle, and that the geomagnetic field is that of an axial, centred dipole, then a magnetic polar wander curve, caused by the postulated continental drift can be predicted using the lithospheric plate rotation poles (Fig. 4).

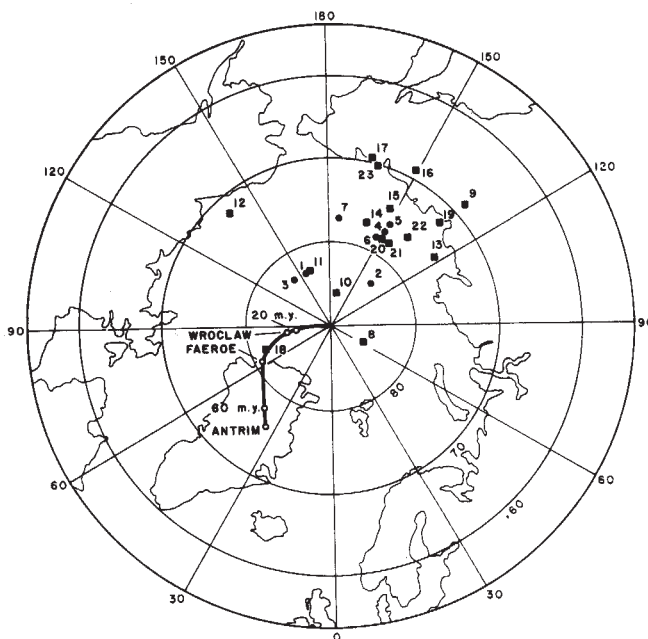


Fig. 5 Polar projection comparing the polar wander curve due to continental drift predicted by the plume-traces (solid line) and the palaeomagnetic data obtained at the actual plume-related volcanic centres. Numbering of poles as in Table 3.

The bulk of the contemporaneous palaeomagnetic data from the European plate comes from plutonic igneous or volcanic centres associated with the plume traces (Table 3). Data from individual plume sites are plotted in Fig. 5, for comparison with the predicted polar wander curve.

The palaeomagnetic pole positions are in relatively good agreement, especially those of Lower Tertiary age; they are, however, all distinctly removed from the position predicted by the plume traces (Fig. 5). Reconciliation of this discrepancy requires true polar wandering: either a rotation of the whole Earth, or a displacement of the magnetic pole.

After correction of observed palaeomagnetic pole positions for the inferred continental drift, any remaining difference from the present geographic pole is theoretically a result of true polar wander. We have "corrected" the Thulean and Eifel palaeomagnetic data by rotating them according to the rotation poles and rotation angles appropriate to the original sampling site in the plume traces (Table 3, Fig. 6). The difference which remains is true polar wandering, applicable in principle to the whole Earth. It can be generally described as involving a displacement of the N pole, since Lower Tertiary time, of

approximately 23° from an original position located along the 123° E meridian. The Upper Tertiary data are more scattered, but have an approximate displacement of 7° along the 150° E meridian.

Based on palaeomagnetic data alone, true wandering of the magnetic pole of $13 \pm 5^\circ$ along the 170° E meridian since early Tertiary time has been suggested by McElhinny and Wellman³⁹. Grommé and McKee⁴⁸ have inferred a similar excursion for the north pole from palaeomagnetic measurements on Tertiary volcanic rocks in the western United States.

Validity of the Model

The most controversial elements of our model are: first, the fact that igneous activity associated with the Eifel plume seems to have occurred contemporaneously over distances of 600 km, and to have continued at individual centres for over 20 m.y. Jackson *et al.*⁴⁹ report evidence from the Hawaiian chain of simultaneous tholeiitic eruptions over distances of 300 km. If activity over even greater distances is indeed characteristic of plume activity on continental crust, then the detection of linear trends in time and space will be extremely difficult, if not impossible.

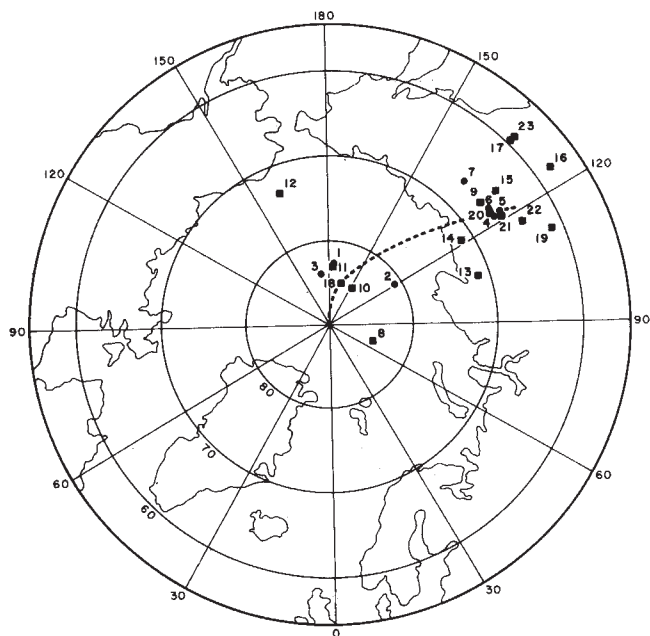


Fig. 6 Polar projection showing location of palaeomagnetic poles corrected for the plume-predicted continental drift. The discrepancy between the corrected palaeo-poles and the present day pole is attributed to true polar wander. (About 23° from a point along the 123° meridian since Lower Tertiary.)

Second, although activity at most of the Scottish Tertiary centres commenced with alkali olivine basalt magmas (Kennedy's Plateau magma type), saturated and oversaturated mafic and felsic rocks are more conspicuous. But in the Eifel plume province, undersaturated, alkalic rocks are most prominent (Tables 1 and 2).

Third, some cratonic igneous activity may result from fracturing or local tectonism or other unknown magma generating agencies, which are quite unrelated to plumes (even if these exist). For example, we have at present no satisfactory explanation for the Upper Tertiary basaltic province of Central France (Massif Central). If there are additional magma generating mechanisms, the pattern of igneous activity would further be confused.

We feel, however, that the weight of the evidence is favour-

able to the model that plumes are relatively stationary in the mantle, and, in addition to producing aseismic ridges in oceans, are responsible for alkalic igneous intrusive-extrusive centres on continents. The hypothesis remains a working one, with many complex and uncertain features. If continental manifestations of plumes can be identified, and conform to the model, then in conjunction with palaeomagnetism, it will be possible to unravel plate motions and distinguish true polar wander in times prior to the oldest existing ocean floor. For this reason, if no other, the concept merits continued consideration and evaluation.

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- ¹ Gilluly, J., *Bull. Geol. Soc. Amer.*, **82**, 2383 (1971).
- ² Morgan, W. J., *Nature*, **230**, 42 (1971).
- ³ Morgan, W. J., *Geol. Soc. Amer. Mem.* (in the press).
- ⁴ Wilson, J. T., *Can. J. Phys.*, **41**, 863 (1963).
- ⁵ Johnson, R. H., and Malahoff, A., *J. Geophys. Res.*, **76**, 3282 (1971).
- ⁶ MacDougall, I., *Nature Physical Science*, **231**, 141 (1971).
- ⁷ Ito, K., and Kennedy, G. C., *Contr. Miner. Petrol.*, **19**, 177 (1968).
- ⁸ Green, D. H., and Ringwood, A. E., *Contr. Miner. Petrol.*, **15**, 103 (1967).
- ⁹ Engel, A. E. J., Engel, C. G., and Haven, R. G., *Bull. Geol. Soc. Amer.*, **76**, 719 (1965).
- ¹⁰ Kay, R., Hubbard, N. J., and Gast, P. W., *J. Geophys. Res.*, **75**, 1585 (1970).
- ¹¹ Oversby, V. M., and Gast, P. W., *J. Geophys. Res.*, **75**, 2097 (1970).
- ¹² Dunham, A., *Geol. J. Special Issue*, **2**, 23 (1970).
- ¹³ Decker, R. W., *Trans. Amer. Geophys. Union*, **52**, 371 (1971).
- ¹⁴ Moorbath, S., Sigurdsson, H., and Goodwin, R., *Earth Plan. Sci. Lett.*, **4**, 197 (1968).
- ¹⁵ Rasmussen, J., and Noe Nygaard, A., *Geol. Surv. Denmark, I Ser.*, **25**, 1 (1970).
- ¹⁶ Tarling, D. H., and Gale, N. H., *Nature*, **218**, 1043 (1968).
- ¹⁷ Miller, J. A., and Mohr, P. A., *Scott J. Geol.*, **1**, 93 (1965).
- ¹⁸ Bennison, G. M., and Wright, A. E., *The Geological History of the British Isles* (St Martins Press, New York, 1969).
- ¹⁹ Moorbath, S., and Bell, J., *J. Petrol.*, **6**, 37 (1965).
- ²⁰ Miller, J. A., and Harland, W. B., *Min. Mag.*, **33**, 521 (1963).
- ²¹ Miller, J. A., and Brown, P. E., *Geol. Mag.*, **102**, 106 (1965).
- ²² Miller, J. A., and Brown, P. E., *Geol. Mag.*, **100**, 93 (1963).
- ²³ Emeleus, C. H., *Proc. Roy. Irish Acad.*, **62B**, 55 (1962).
- ²⁴ Knetsch, G., *Geologie von Deutschland* (Ferdinand Enke Verlag, Stuttgart, 1963).
- ²⁵ Dorn, P., *Geologie von Mitteleuropa* (Schweizerbartsche, Stuttgart, 1960).
- ²⁶ Schottler, W., *Der Vogelsberg, Notizbl. Ver. Erdk. Hess. Geol. Landesanstalt, Darmstadt*, 1937).
- ²⁷ Brinkmann, R., *Geol. Rdsch.*, **57**, 148 (1967).
- ²⁸ Schroder, B., *Geol. Rdsch.*, **55**, 530 (1965).
- ²⁹ Zartner, W. R., *Geologie des Duppauer Gebirges, I. Nordhalte. Abh. Dt. Ges. Wiss. Kunst. Prague, Math.-Naturwiss.*, Ab 2, Prag. (1938).
- ³⁰ Todt, W., thesis, University of Heidelberg (1971).
- ³¹ Pietsch, K., *Geologie von Sachsen*. (VEB Deutscher, Berlin, 1962).
- ³² Nairn, A. E. M., *Geol. Rdsch.*, **56**, 408 (1967).
- ³³ Schwarzbach, M., *Geol. Rdsch.*, **34** (1943).
- ³⁴ Urry, W. D., *Bull. Geol. Soc. Amer.*, **47**, 1217 (1936).
- ³⁵ Birkenmajer, K., and Nairn, A. E. M., *Geol. Rdsch.*, **58**, 697 (1969).
- ³⁶ Le Pichon, X., Hyndman, R. D., and Pautot, G., *J. Geophys. Res.*, **76**, 4724 (1971).
- ³⁷ Laughton, A. S., *Nature*, **232**, 612 (1971).
- ³⁸ Książkiewicz, M., Samsonowicz, I., and Ryhle, E., *An Outline of the Geology of Poland* (Warsaw, 1968).
- ³⁹ McElhinny, M. W., and Wellman, P., *Earth Plan. Sci. Lett.*, **6**, 198 (1969).
- ⁴⁰ Irving, E., *Paleomagnetism, and Its Application to Geological and Geophysical Problems* (Wiley, New York, 1964).
- ⁴¹ Tarling, D. H., in *Paleogeophysics* (edit. by Runcorn, S. K.) (Academic Press, London, New York, 1970).
- ⁴² Wilson, R. L., *Geophys. J. R. Astr. Soc.*, **19**, 417 (1970).
- ⁴³ Creer, K. M., *Sci. Rev.*, **6**, 369 (1970).
- ⁴⁴ Bock, G., and Soffel, H., *Z. Geophys.*, **37**, 581 (1971).
- ⁴⁵ Nairn, A. E. M., *Travaux de L'Institut Geophysique de l'Academie Tchecoslovaque des Sciences No. 252* (Geofysikalni, Sbornik, 1966).
- ⁴⁶ Nairn, A. E. M., and Vollstadt, H., *Geol. Rund.*, **57**, 385 (1967).
- ⁴⁷ Wilson, R. L., *Geophys. J. R. Astr. Soc.*, **20**, 1 (1970).
- ⁴⁸ Grommé, C. S., and McKee, E. H., *Trans. Amer. Geophys. Un.*, **52**, No. 4, 187 (1971).
- ⁴⁹ Jackson, E. D., Silver, E. A., and Dalrymple, G. B., *Bull. Geol. Soc. Amer.*, **83**, 601 (1972).

Stability of *X* Chromosomal Inactivation in Human Somatic Cells

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Using human somatic cell/mouse cell hybrids, no evidence for reactivation of the silent *X* chromosome in human somatic cells has been obtained.

EVIDENCE supporting the Lyon hypothesis^{1,2} leaves little doubt that one of the two *X* chromosomes in normal female somatic cells is inactive and the mechanism involved may be revealed by a means to reverse the process. Comings³ briefly exposed cultured fibroblasts from uterine leiomyomas, which are clonal in origin, to various physical and chemical agents, some known to stimulate RNA synthesis, but none induced *X* reactivation. I have attempted to activate the silent *X* by producing interspecific cell hybrids and by using selective media. The model involves single cell clones of skin fibroblasts derived from females heterozygous for the common A and B electrophoretic variants of glucose-6-phosphate dehydrogenase (G6PD). Each *X* chromosome is marked by a protein that can be identified by electrophoresis. Clones showing only one G6PD variant⁴ can be treated in various ways, and a reactivated *X* would be revealed by acquisition of the second enzyme marker.

Harris *et al.*⁵ observed that relatively differentiated nuclei in which the synthesis of DNA, RNA or both has been suppressed, can be induced to resume synthesis by fusion with less differentiated cells of another species. I have therefore investigated whether fusion of human female somatic cells with mouse cells influences the activity of genes on either human *X*.

The human parental line was a clonal population of skin fibroblasts with the G6PD AB genotype, but showing only the G6PD A phenotype, since the G6PD B gene was on the inactive chromosome. The mouse fibroblast line A₉ (ref. 6) was used as partner. Four independently isolated HAT-resistant* clones were maintained in HAT medium and analysed regularly

during the subsequent year for their G6PD electrophoretic phenotype⁹.

Analysis of G6PD phenotype 8 weeks after fusion revealed the hybrid nature of the clones (Fig. 1). Each had both parent isozymes and also the heteropolymer made up of murine and human A subunits. Neither initially, nor during the following year, however, was there evidence of G6PD B isozyme or heteropolymers resulting from reassociation of A and B subunits.



Fig. 1 G6PD phenotype of hybrids. Slots 1 and 6: uncloned human fibroblasts G6PD AB (source of the parent G6PD A clone). Slots 5 and 10: mouse parent (Ag). Slots 2, 3, 7, 8, and 9: hybrid clones.

* The media used in these experiments were as follows. (1) Growth medium: MEM enriched with non-essential amino-acids and 20% human serum. (2) HAT: growth medium+hypoxanthine (10^{-4} M), aminopterin (4×10^{-7} M), thymidine (1.6×10^{-5} M), and glycine (3×10^{-6} M). Aminopterin blocks *de novo* purine synthesis, forcing the cell to use the alternative pathway which requires HGPRT; therefore, only HGPRT⁺ cells can divide⁶. (3) Azaserine: growth medium+azaserine (2.9×10^{-5} M) which blocks *de novo* purine synthesis, so like HAT, selects against HGPRT⁻ cells⁷. (4) 6-Thioguanine: growth medium+6-thioguanine (6×10^{-5} M), a purine analogue which, after conversion by HGPRT to its nucleotide, is lethal to HGPRT⁺ cells.

The failure to find hybrids expressing the human G6PD B allele may be attributable to the lack of reactivation of the pertinent *X* or to its loss. Although the mating favoured the retention of human *X* chromosomes, unless the inactive *X* became active, it would contribute nothing advantageous to the hybrid and might be one of the first human chromosomes lost. On the other hand, if reactivated, it should have been retained since the selective system used favours retention, at least initially, of both human *X* chromosomes^{10,11}. In any event, if activated, the *X* with the human G6PD B allele might

have been the one expressed in the hybrid. Thus, it seems that cell fusion failed to stimulate the inactive *X*.

The lack of reactivation could be related to the fact that both parental cells are mammalian, with a common method of sex dosage compensation. Derepression of a human *X* chromosome in the mouse-human hybrid may be impossible because the mouse *X* is presumably under similar regulation.

Inasmuch as G6PD is *X*-linked in the mouse¹², the presence of the murine enzyme in these hybrids indicates that *X* inactivation is not maintained by diffusible intracellular repressor-like substances unless these are species specific.

Although the inactivation of one *X* is the rule, possibly in rare cells both *X*s are functioning, perhaps as a result of mutation involving regulation of the inactivation process. Even if two responsive *X*s do not occur in normal growth conditions, reactivation might be induced as the result of selective pressure. Since only the active *X* determines the phenotype, cells heterozygous for HGPRT deficiency fall into two populations; one with HGPRT activity which can divide in HAT but not in 6-thioguanine (6TG), and the other lacking HGPRT and thereby able to proliferate in 6TG but not in HAT¹³. The questions arose as to whether any progeny of the latter (HGPRT⁺ on the inactive chromosome) are able to proliferate in HAT, since to survive the cell has only to turn on the previously silent gene.

Table 1 HGPRT Phenotype of Clones from Doubly Heterozygous Cell Lines (76 and 81) in Growth and Selective Media

Cell line	Medium	Clones observed	HGPRT phenotype	
			%+	%-
76	Growth	213	81	19
	HAT	65	100	0
81	Growth	180	73	27
	6TG	21	0	100

I used skin fibroblasts heterozygous for the A and B variants of G6PD as well as for HGPRT deficiency¹⁴ (Fig. 2), since of the possible mechanisms leading to HAT-resistant clones, only *X* reactivation would result in the expression in a single clone of both G6PD alleles. The relation between HGPRT and G6PD alleles in these heterozygous fibroblasts was established by autoradiography¹³ and electrophoresis. Without exception the HAT-resistant clones were HGPRT⁺, while those surviving in 6TG had the mutant phenotype (Table 1). Moreover, all clones isolated in 6TG were G6PD A, while those selected in media permitting growth of only HGPRT⁺ cells were G6PD B (Table 2). The invariable association of G6PD A and HGPRT⁻, as well as of G6PD B and HGPRT⁺ alleles, confirmed expectations based on pedigree analysis (Fig. 2) and studies of hair follicles¹⁵, that in these cells HGPRT⁻ and G6PD A are on the same *X* (*cis*).

Table 2 G6PD Phenotype of 157 Clones from Doubly Heterozygous Cell Line 76 isolated in Growth and Selective Media

Medium	No. of clones	%A	%B
Growth	6	16	48
6-Thioguanine	125	100	0
HAT	22	0	100
Azaserine	4	0	100

Clones isolated in 6TG and therefore phenotypically HGPRT⁻ G6PD A were tested for HAT resistance. The increase in cell population from 10³ at clonal isolation to

1–2 × 10⁶ at testing, involved sufficient time in growth medium for reactivation to occur and be expressed in absence of selective pressures. More than 10⁷ cells were plated (10⁵ cells/60 mm Petri dish) into HAT medium and selection was maintained for several weeks (Table 3). Since not one HAT-resistant colony was observed, the results provide no evidence for the existence of HGPRT⁺ progeny of phenotypically HGPRT⁻ cells.

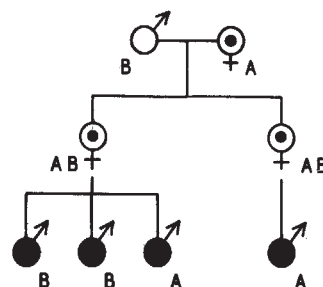


Fig. 2 Partial pedigree of HFJ kindred showing pertinent HGPRT and G6PD genotypes derived from data in the present study and that reported by Nyhan *et al.*¹⁴. ♂, Males with Lesch-Nyhan syndrome; ♀, heterozygotes; A, B, AB, G6PD genotype. Both heterozygotes studied received from their father the *X* chromosome containing G6PD B and HGPRT⁺ loci, and from their mother the *X* with the G6PD A and HGPRT⁻ loci. Sons who are G6PD B HGPRT⁻ represent recombinants.

The sensitivity of HAT as an indicator of HGPRT⁺ cells was determined by testing mixtures of ten cells from a normal HGPRT⁺ female with 10⁴–10⁵ HGPRT⁻ cells from a Lesch-Nyhan male (Fig. 3a). More HAT-resistant clones were found in mixed populations than when ten HGPRT⁺ cells were plated alone. That several HAT-resistant clones were karyotypically male and therefore HGPRT⁻ in origin, indicates that some of the enrichment of HAT-resistant colonies results from cross-feeding of HGPRT⁻ by HGPRT⁺ cells¹⁶, thus enhancing the sensitivity of HAT as an indicator of exceptional HGPRT⁺ cells. Unfortunately cross-feeding decreases the sensitivity of selection for forward mutations at this locus (Fig. 3b). Consequently, tests of mutagenic activity contingent on the selection of rare HGPRT⁻ cells among wild-type human fibroblasts provide only a minimal estimate of the frequency of these mutations¹⁷.

Table 3 Selection for HGPRT⁺ Cells in Progeny Clones with HGPRT⁻ Phenotype

Clones	Selective agent	Cells plated	Days observed	Clones observed
1 *	Azaserine	1.20 × 10 ⁶	15	0
2–6	HAT	1.13 × 10 ⁷	28–30	0

* Clones were derived from doubly heterozygous line 76 and are of HGPRT⁻, G6PD A phenotype.

The concept of a physically as well as functionally single active *X*, implicit in the Lyon hypothesis, is supported by the relationship between numbers of late replicating chromosomes and *X*s and by the consistent pattern of inactivation in clones of females heterozygous for both G6PD and phosphoglycerate kinase electrophoretic variants¹⁸. In the present study the coupling phase of the two sets of alleles is known, so that the invariable association of G6PD A with HGPRT⁻ in progeny of individual cells demonstrates that the two alleles located

on the same *X* chromosome (*cis*) are inactive or active simultaneously, and is compelling evidence for a single active *X*.

Although both are specified by the *X*, G6PD and HGPRT are loosely linked, as indicated by the frequency of meiotic recombinants in the family sampled¹⁴ (Fig. 2). Accordingly, crossing-over, if it occurs at all in somatic cells, should take place between these loci. The absence of recombinants among 1.25×10^7 skin fibroblasts analysed may be attributable to difficulties inherent in recovering clones, or to the size of the population sampled. The frequency of somatic recombination within the white locus of *Drosophila melanogaster* is less than 1 or 2 in 2×10^6 mitoses¹⁹. My results, however, may indicate that asynchronous replication, or the mechanism maintaining

Received May 16; revised June 23, 1972.

- ¹ Lyon, M., *Amer. J. Human Genet.*, **14**, 135 (1962).
- ² Lyon, M. F., *Nature New Biology*, **232**, 229 (1971).
- ³ Comings, D. E., *Lancet*, ii, 1137 (1966).
- ⁴ Davidson, R. G., Nitowsky, H. M., and Childs, B., *Proc. US Nat. Acad. Sci.*, **50**, 481 (1963).
- ⁵ Harris, H., Watkins, J. F., Ford, C. E., and Schoeff, G. I., *J. Cell Sci.*, **1**, 1 (1966).
- ⁶ Littlefield, J. W., *Nature*, **203**, 1142 (1964).
- ⁷ Szybalski, E. H., and Ragni, G., *Nat. Cancer Inst. Monog.*, No. 7, 75 (1962).
- ⁸ Siniscalco, M., Klinger, H. P., Eagle, H., Koprowski, H., Fujimoto, W. Y., and Seegmiller, J. E., *Proc. US Nat. Acad. Sci.*, **62**, 793 (1969).

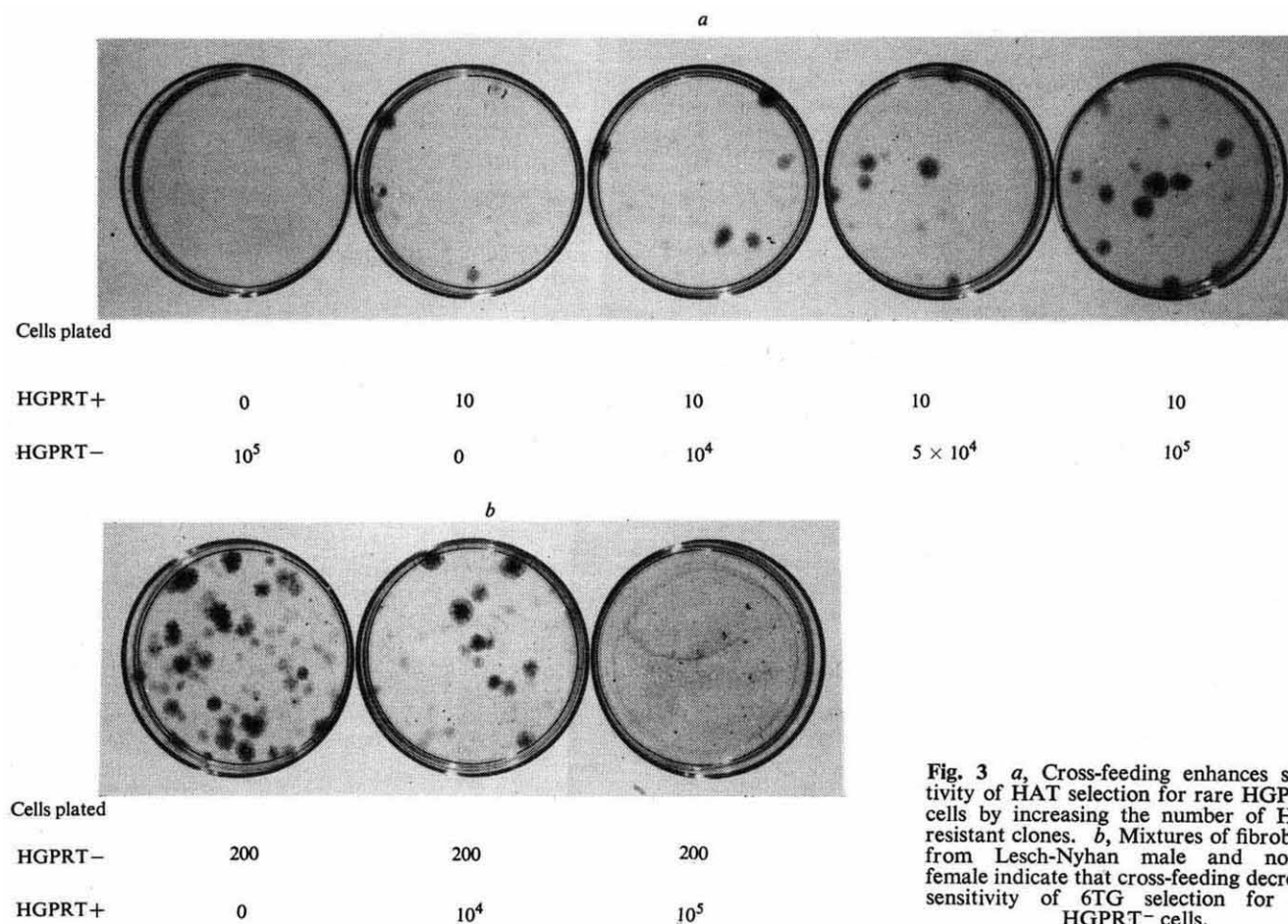


Fig. 3 *a*, Cross-feeding enhances sensitivity of HAT selection for rare HGPRT⁺ cells by increasing the number of HAT-resistant clones. *b*, Mixtures of fibroblasts from Lesch-Nyhan male and normal female indicate that cross-feeding decreases sensitivity of 6TG selection for rare HGPRT⁻ cells.

X inactivation, might suppress recombination between active and repressed *X*.

The results reported here demonstrate the stability of *X* inactivation in human diploid cells. Neither fusion with mouse cells nor exposure to selective pressure was able to reveal or induce reversal of the inactivation. At the same time, the immutability of the HGPRT phenotype indicates that spontaneous reverse mutation at this locus is not a frequent event, at least in the cells analysed.

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- ⁹ Porter, I. H., Boyer, S. H., Watson-Williams, E. J., Adam, A., Szeinberg, A., and Siniscalco, M., *Lancet*, i, 895 (1964).
- ¹⁰ Migeon, B. R., and Miller, C. S., *Science*, **162**, 1005 (1968).
- ¹¹ Green, H., Wang, R., Kehinde, R., and Meuth, M., *Nature New Biology*, **234**, 138 (1971).
- ¹² Epstein, C. J., *Science*, **163**, 1078 (1969).
- ¹³ Migeon, B. R., *Biochem. Genet.*, **4**, 387 (1970).
- ¹⁴ Nyhan, W. L., Bakayk B., Connor, J. D., Marks, J. F., and Keele, D. K., *Proc. US Nat. Acad. Sci.*, **65**, 214 (1970).
- ¹⁵ Goldstein, J. L., Marks, J. F., and Gartler, S. M., *Proc. US Nat. Acad. Sci.*, **68**, 1425 (1971).
- ¹⁶ Bürk, R. R., Pitts, J. D., and Subak-Sharpe, J. H., *Exp. Cell Res.*, **53**, 297 (1968).
- ¹⁷ Albertini, R. J., and DeMars, R., *Science*, **169**, 482 (1970).
- ¹⁸ Gartler, S. M., Chen, S.-H., Fialkow, P. J., and Giblett, E. R., *Nature New Biology*, **236**, 149 (1972).
- ¹⁹ Stern, C., *Genetics*, **62**, 573 (1969).

LETTERS TO NATURE

PHYSICAL SCIENCES

Observed Energy Distribution of α Lyra and β Cen at 2000–3800 Å

THE space astrophysical observatory Orion, installed in the orbital station Salyut, has provided several slitless spectrograms of α Lyra and β Cen between wavelengths 2000 and 3800 Å. The spectrograms were obtained in June 1971 with the help of a mirror telescope of the Mersenn system and a spectrograph of the Wadsworth system using film sensitive in the far ultraviolet. The dispersion of the spectrograph is 32 Å/mm, while the resolution of the spectrograms derived is about 5 Å on 2600 Å. A detailed description of the Orion apparatus and the method of obtaining the spectrograms have been given elsewhere^{1–3}.

Before installation the telescope and spectrograph were calibrated using synchrotron radiation from an electron accelerator³. We also allowed for astigmatism to obtain the true energy distribution in the spectra of α Lyra (AO V) and β Cen (B1 II) in the region 3800 to 2000 Å (Figs. 1 and 2). Curves of theoretical distribution of continuous spectra corresponding to the various models of stellar photospheres are also plotted in Figs. 1 and 2. In the case of α Lyra the following calculated models have been used: by Schild *et al.*⁴, $T_{\text{eff}} = 9,650$ K, $\log g = 4.05$; by Mihalas⁵, $T_{\text{eff}} = 10,080$ K, $\log g = 4$; by Strom and Avrett⁶, $T_{\text{eff}} = 10,000$ K, $\log g = 4$, $x = 0.83$. In the case of β Cen two models have been used: Mihalas⁵, $T_{\text{eff}} = 24,000$ K, $\log g = 4$; and Van Citters and Morton⁷, $T_{\text{eff}} = 22,000$ K, $\log g = 4$.

The observed distribution of energy in the spectrum of α Lyra (Vega) in the region 3800 to 2000 Å is in good accordance with theoretical models. Within the precision range of our measurements (0.15 mag) no priority should be given to any

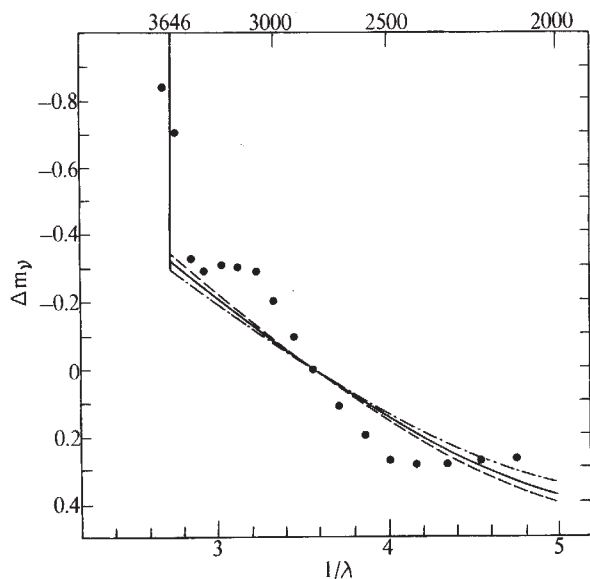


Fig. 1 Energy distribution for α Lyra. Corrections for astigmatism have been applied. Data from Schild *et al.*⁴ (---), Mihalas⁵ (—) and Strom and Avrett⁶ (---). ● ● ●, Our observations.

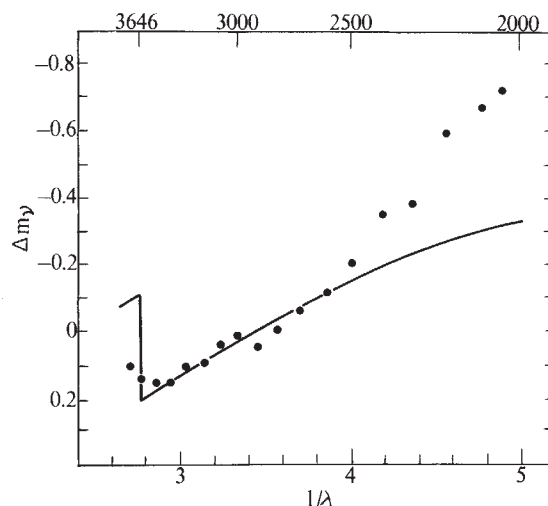


Fig. 2 Energy distribution for β Cen, with astigmatism corrections. —, Data from Van Citters and Morton⁷, and Mihalas⁵. ● ● ●, Our observations.

of the three models. In future α Lyra can be used as a convenient and reliable spectrophotometric standard in the region of wavelengths shorter than 3000 Å at least down to 2000 Å.

In the case of Agena (β Cen) our observations confirm the occurrence of a jump in the continuous spectrum on the limit of the Balmer continuum. On the other hand, in the interval of wavelengths 3700–2400 Å we have a good accordance between observed and computed distributions of the energy in Agena. But in the region below 2400 Å a considerable difference has been found between observed and theoretical distributions, the observations giving greater energy as compared with theory. The difference increases in the direction of short waves and at 2000 Å it is roughly 0.4 mag, nearly 1.5 on the intensity scale. The probable error of the measurements does not exceed 0.2 mag. So this discrepancy may be real, the results of the lack of correspondence between the assumptions underlying the theoretical models and the state of the photosphere in β Cen, which is a bright giant endowed with a luminosity of the second class. But additional observations are required before a final conclusion is reached.

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- Gurzadyan, G. A., and Ohanesyan, J. B., *Space Sci. Revs.* (1972, in the press).
- Patzaev, V. I., Ohanesyan, J. B., and Gurzadyan, G. A., *Commun. Burakan Observ.*, **45** (1972).
- Gurzadyan, G. A., Ohanesyan, J. B., and Efremyan, R. A., *Commun. Burakan Observ.*, **45** (1972).
- Schild, R., Peterson, D. M., and Oke, J. B., *Astrophys. J.*, **166**, 95 (1971).
- Mihalas, D., *Astrophys. J., Suppl.*, **9**, 321 (1965).
- Strom, S. E., and Avrett, E. H., *Astrophys. J., Suppl.*, **12**, 1 (1965).
- Van Citters, G. W., and Morton, D. C., *Astrophys. J.*, **161**, 695 (1970).

Occultation of Sgr A

INTERFEROMETRIC^{1,2} and lunar occultation³⁻⁵ observations show that the radio source Sgr A, which is located near the galactic centre, consists of several components varying in size from a few arc s to a few arc min. Lunar occultation observations made at Ootacamund on September 9, 1970, have provided detailed information on the structure of the source of 327 MHz and have revealed the presence of an extended component 10×4 arc min in size and centred approximately on Sgr A. The extended source has an inclination of $45^\circ \pm 15^\circ$ to the galactic plane, similar to that of the 20 cm continuum ridges⁶.

The observations were made using the Ooty radio telescope⁷ operating at 327 MHz with a bandwidth of 4 MHz and a time constant of 1 s. The telescope provides twelve simultaneous total power and phase-switched beams with half power widths of 2° in right ascension and 6.4 and 4.5 arc min respectively in declination. The beams are separated in declination of 3.4 arc min towards Sgr A. Simultaneous occultation profiles were thus obtained for twelve different declinations around the source. The occultation curve for the phase-switched beam that tracked Sgr A is shown, after smoothing the data with a gaussian function of half-power width 4 min, in Fig. 1. The small

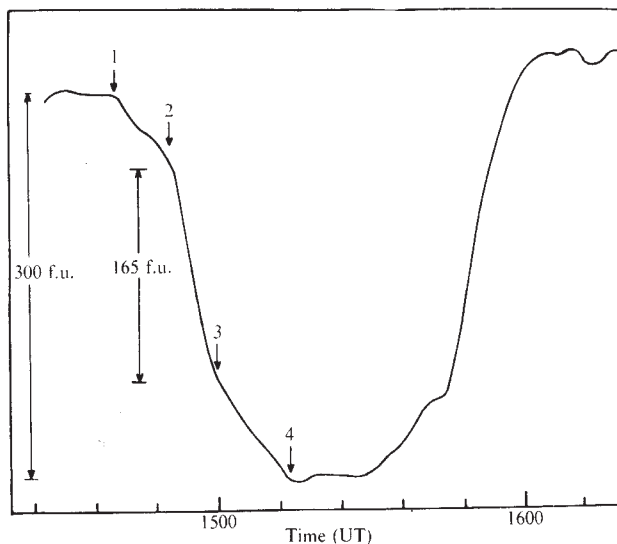


Fig. 1 The lunar occultation record of Sgr A for the phase switched beam. A gaussian smoothing of 4 min has been applied. Numbers 1 to 4 mark the change of gradient corresponding to the disappearance of the source Sgr A-E and Sgr A, as shown also in Fig. 2.

difference in the power levels at the beginning and end of the record arises from the Moon's drift in declination by about 7 arc min across a hot background with an estimated brightness temperature of about 1,000 K.

Strip brightness distributions across Sgr A at 327 MHz are presented in Fig. 2. These were derived by first differentiating the disappearance and reappearance curves for the total power and phase switched beams and then smoothing by means of a gaussian function with a half power width of 4 min to reduce the effect of the ionospheric scintillation during the observations. Position angles of scans at disappearance and reappearance lie almost across and along the galactic plane, respectively. The resolution obtained for both the scans is close to 1 arc min. The total power and phase switched curves show good agreement; the differences could have arisen partly because of different beam shapes and partly because of ionospheric scintillation. A mean of the two curves has been taken to represent the brightness distribution at each position angle. The distributions show a peak corresponding to the source

Sgr A superimposed on an extended component, E, indicated by the broken line in Fig. 2. This extended source Sgr A-E is clearly evident on the occultation records, for both phase switched (Fig. 1) and total power beams, where a gradual change in the received power can be seen before and after the steeper gradient corresponding to the occultation of the central 3 arc min source Sgr A. The occultation records of Thompson *et al.*³ at 405 MHz (private communication) also indicate a wider component surrounding the central source, with an estimated flux density of about 200 f.u. and a size of 10 to 20 arc min. Thompson *et al.* were, however, unable to interpret this broad component because the beam of their antenna was larger than the Moon and confusion arising from occultations of the outer regions of the source complex were to be expected during the period of observation. By contrast, the Ooty radio telescope has a beamwidth of less than 6.4 arc min in declination for the total power and phase switched beams and therefore such confusion is not appreciable. Further, the changes in the base line are negligible in the case of the phase switched beams.

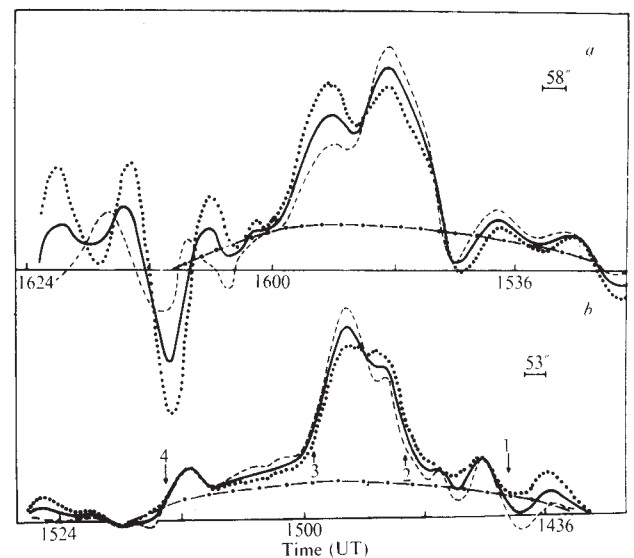


Fig. 2 Strip brightness distributions across Sgr A, obtained by differentiating the occultation records. Effective resolutions are indicated by bars. — — —, Phase-switched; . . . , total power; —, mean of the two curves; — · —, extended component Sgr A-E. a, Reappearance PA 208° ; b, disappearance PA 131° .

The extended source Sgr A-E has not been recognized in any of the maps made with narrow pencil beams at higher radio frequencies⁸⁻¹⁰. This might be due partly to its steep spectrum and partly to the confusion caused by the strong Sgr A source. Maxwell and Taylor⁵ have shown that measurements made with resolutions of ~ 10 arc min give a spectral index of ~ 0.65 for Sgr A. These measurements are, however, likely to include components other than the central source and Sgr A-E, for they indicate rather large values of flux density for the source complex. Pariiskii¹¹ has reported east-west strip scans across Sgr A at wavelengths of 3.2 and 9.4 cm with respective fan beams of 1.1×40 arc min and 3.7×120 arc min, which show a broad component of size about 15 arc min to the east of the central source. By taking equivalent strip scans across the brightness distribution map published by Downes and Maxwell⁸ we find that Pariiskii's broad component arises mainly from the thermal sources G 0.2-0.0 and G 0.1-0.0.

The source Sgr A-E has a flux density of 135 ± 30 f.u. at 327 MHz. The receiver system was calibrated on the source PKS 1309-22, taking its flux density as 19.6 f.u. at 327 MHz. The source Sgr A-E has half power widths of 10 ± 2 arc min and 4 ± 1 arc min along its major and minor axes respectively. Its half-power size and orientation, as shown in Fig. 3 by

broken line, were determined by plotting the Moon's limbs at appropriate times during disappearance and reappearance and also by considering the response from the source in the occultation records of the neighbouring beams. The derived position (1950.0) of the source is: RA = 17 h 42 m 32 s $\pm$ 6 s and dec. = $28^\circ 59.5' \pm 1'$. Its major axis is inclined to the galactic plane by $45^\circ \pm 15^\circ$.

For Sgr A (excluding Sgr A-E) the size at 327 MHz is found to be 100 ± 25 arc s and 170 ± 35 arc s along position angles 131° and 208° respectively. The position of the principal peak (component A) and of the centroid at 327 MHz are both given in Table 1 together with values obtained by others at different frequencies. There is evidently no appreciable shift in position with frequency.

By combining the occultation observations of Sandqvist⁴ at 1,665 MHz and the interferometric observations of Downes and Martin¹ at 1,420 MHz, we have constructed an approximate contour diagram of brightness distribution across Sgr A which is shown in Fig. 3, together with the strip brightness distributions at 327, 405, 1,420 and 1,665 MHz plotted along respective position angles. Areas of the curves have been made proportional to the measured flux densities. A comparison of these curves leads us to conclude that the brightness distribution remains almost unchanged between 327 and 1,665 MHz.

The source Sgr A has two peaks superimposed on a background B as shown in Fig. 3; the peaks have been marked as A and S, following the nomenclature by Sandqvist⁴. Downes and Martin¹ have divided the source into two components, Sgr A West and Sgr A East, which seem to correspond to components A and (B+S), respectively, of Fig. 3. Their division is somewhat arbitrary but appears physically meaningful for two reasons; first, the $+40$ km s⁻¹ OH and CH₂O clouds^{4,12} have centroids lying close to peak S and both have sizes similar to that of (B+S), suggesting a physical association; second, the component A (Sgr A West) has a flatter spectrum (see later) and its position coincides with the infrared source¹³ which is believed to lie near the galactic centre.

The flux density of Sgr A (A+B+S) at 327 MHz is found to be 165 ± 30 f.u. Its spectrum, based on high resolution observations, is plotted in Fig. 4, from which we find a spectral index α (defined as $S \propto \nu^{-\alpha}$) of about 0.25 at higher frequencies. It is difficult to estimate the flux of components A, B and S separately but it seems unlikely that either of these has a spectral index $\alpha > 0.3$. According to Downes and Martin¹, Sgr A West (component A) contributes about 20% to the total flux density of the source; its spectral index seems to be somewhat flatter with a value of about 0.1 ± 0.1 in the frequency range 327 to 5,000 MHz. The similar spectra for the three components suggest that they are all located near the galactic centre including the OH and CH₂O clouds^{4,12}.

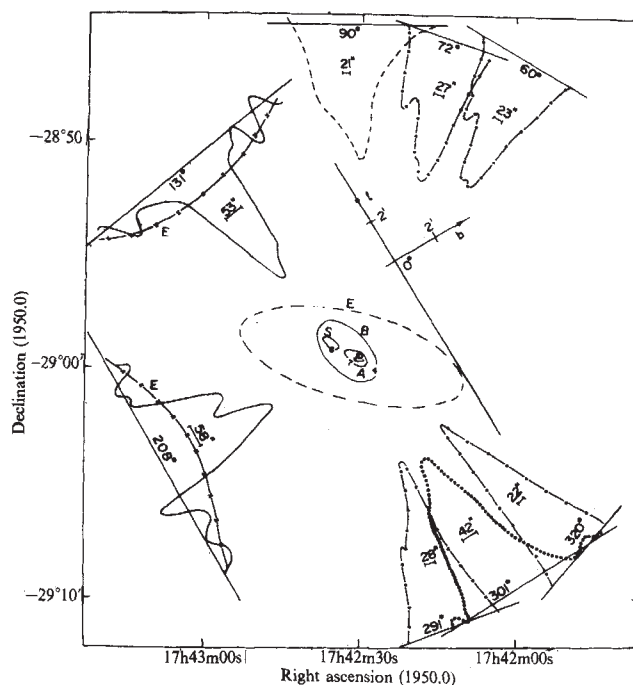


Fig. 3 Strip brightness distributions for Sgr A, plotted along respective position angles, for observations at 327 MHz, 405 MHz (ref. 3), 1,420 MHz (ref. 1) and 1,665 MHz (ref. 4). Areas of the curves are proportional to their measured flux densities and effective resolutions are indicated by bars. An approximate brightness contour map derived from observations at 1,420 MHz (ref. 1) and 1,665 MHz (ref. 4) is shown in the centre. The source Sgr A-E seen at 327 MHz, is shown in the centre by a broken line. —, 327 MHz; ···, 405 MHz; ---, 1,420 MHz; -·-·-, 1,665 MHz.

The spectrum of Sgr A shows a steep cutoff at low frequencies, as a result of free-free absorption in weak HII regions or cold clouds in the intervening medium^{14,15}. From a comparison of the measured flux density at 327 MHz with the expected value obtained by extrapolating the high frequency spectrum ($\alpha=0.25$) we estimate an optical depth τ of ~ 0.6 for the absorbing medium which is consistent with $\tau > 4$ estimated by Dulk¹⁴ from observations at 80 MHz. From an analysis of the occultation records for all twelve beams we find optical depths of about 3.5 and 0.3 for the thermal source G 0.2-0.0 and the $1^\circ \times 0.4^\circ$ extended thermal source⁸ respectively. These two thermal sources could give rise to the observed absorption of Sgr A emission at low frequencies. The required value of

Table 1 Position (1950.0) of the Central Sgr A Source

Reference	1	Frequency (MHz)	2	Right ascension 17 h 42 m	Declination $-28^\circ 59'$
Present work	LO	327	C	31.7 ± 1 s	14 ± 15 arc s
			P	30.5 ± 1 s	35 ± 15 arc s
Thompson <i>et al.</i> ³	LO	405	C*	33.3 ± 1.5 s	06 ± 20 arc s
Downes and Martin ¹	I	1,420	C*	31.4 ± 1 s	10 ± 60 arc s
			P	29.3 ± 0.3 s	15 ± 50 arc s
Maxwell and Taylor ⁵	LO	234 to 2,388	C	30.6 ± 1 s	14 ± 15 arc s
Sandqvist ⁴	LO	1,665	C*	33.3 ± 1.5 s	25 ± 20 arc s
			P	30.4 ± 1 s	31 ± 15 arc s
Becklin and Neugebauer ¹³	PB	2.2 μ m		30.0 ± 1 s	24 ± 6 arc s
Mean occultation position	LO		C	32.2 ± 1 s	15 ± 15 arc s
			P	30.5 ± 1 s	33 ± 15 arc s

1: LO=Lunar occultation, I=interferometry and PB=pencil beam observations.

2: C=Centroid and P=peak of the brightness distribution of the central Sgr A source.

* Estimated by us from their published data.

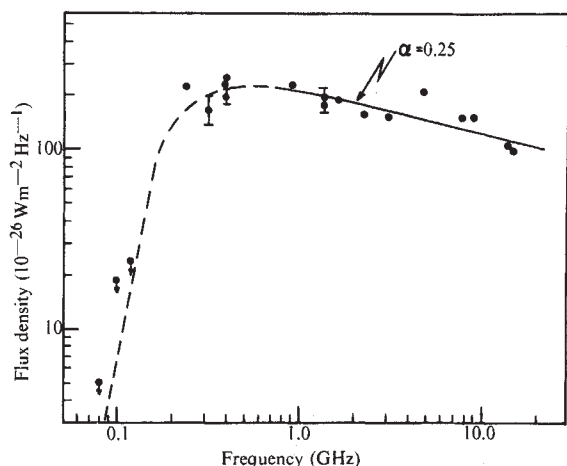


Fig. 4 Spectrum of Sgr A. The arrows represent estimated upper limits to flux densities at various frequencies. The adopted flux densities at 5 and 14.5 GHz have been estimated by Downes and Maxwell⁸ from the published data^{9,19}. The broken curve shows the effect on the spectrum ($\alpha=0.25$) of free-free absorption in the medium with an assumed optical depth $\tau=6$ at 80 MHz.

emission measure for an electron temperature of 5,000 K is about 6×10^4 pc cm⁻⁶, which is not incompatible with the recombination line observations¹⁶⁻¹⁸.

On a synchrotron interpretation, Sgr A and the extended source Sgr A-E have equipartition energies of about 10^{49} erg. To maintain a flat spectrum against inverse Compton losses within the source, injections of energetic particles are required either continuously or recurrently every $<10^5$ yr. The source Sgr A-E is likely to have a steeper spectrum and could have arisen from the diffusion of relativistic electrons out of the central source. It is interesting that Sgr A-E has the same inclination to the galactic plane as the inclined ridges, extending to about 1° away from the galactic centre in the 20 cm continuum map of Kerr and Sinclair⁶. There is also evidence of a broad structure, comprising a few secondary sources in infrared observations¹³ at 2.2 cm, indicating the presence of matter in the same orientation as the source Sgr A-E.

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- ¹ Downes, D., and Martin, A. H. M., *Nature*, **233**, 112 (1971).
- ² Ekers, R. D., and Lynden-Bell, D., *Astrophys. Lett.*, **9**, 189 (1971).
- ³ Thompson, A. R., Riddle, A. C., and Lang, K. R., *Astrophys. Lett.*, **3**, 49 (1969).
- ⁴ Sandqvist, A., thesis, Univ. Maryland (1971).
- ⁵ Maxwell, A., and Taylor, J. H., *Astrophys. Lett.*, **2**, 191 (1968).
- ⁶ Kerr, F. J., and Sinclair, M. W., *Nature*, **212**, 166 (1966).
- ⁷ Swarup, G., Sarma, N. V. G., Joshi, M. N., Kapahi, V. K., Bagri, D. S., Damle, S. H., Ananthakrishnan, S., Balasubramanian, V., Bhawe, S. S., and Sinha, R. P., *Nature Physical Science*, **230**, 185 (1971).
- ⁸ Downes, D., and Maxwell, A., *Astrophys. J.*, **146**, 653 (1966).
- ⁹ Broten, N. W., Cooper, B. F. C., Gardner, F. F., Minnet, H. C., Price, R. M., Tonking, F. G., and Yabsley, D. E., *Austral. J. Phys.*, **18**, 85 (1965).
- ¹⁰ Downes, D., Maxwell, A., and Meeks, M. L., *Nature*, **208**, 1189 (1965).
- ¹¹ Pariiskii, Y. N., *Soviet Phys. Dokl.*, **4**, 1172 (1959).
- ¹² Gardner, F. F., and Whiteoak, J. B., *Astrophys. Lett.*, **10**, 171 (1972).
- ¹³ Becklin, E. E., and Neugebauer, G., *Astrophys. J.*, **151**, 145 (1968).
- ¹⁴ Dulk, G. A., *Astrophys. Lett.*, **7**, 137 (1970).

- ¹⁵ Brezgunov, V. N., Dagkesamansky, R. D., and Udaltsov, V. A., *Astrophys. Lett.*, **9**, 117 (1971).
- ¹⁶ Mezger, P. G., and Hoglund, B., *Astrophys. J.*, **147**, 490 (1967).
- ¹⁷ Dravskii, A. F., Dravskii, Z. V., Turevskij, V. M., and Solonikov, A. A., *Astr. Cirk. Izdav. Bjuro Astr. Soobsc. Kazan*, No. 354 (1966).
- ¹⁸ Riegel, K. W., and Kilston, S. D., *Astrophys. J.*, **159**, L155 (1970).
- ¹⁹ Baars, J. W. M., Mezger, P. G., and Wendker, H., *Z. Astrophys.*, **61**, 134 (1965).

Glacier Movement measured with a Radio Echo Technique

In the radio echo sounding method for measuring the thickness of polar ice masses, the sounder transmits regular pulses each containing several cycles of VHF radio waves into the ice. Usually the glacier bed is rough so the echo is a distorted version of the transmitted pulse: it is lengthened and the amplitude and phase of the carrier wave vary within its length (Fig. 1). The echoes also vary rapidly with horizontal displacement of the radio echo sounder¹, and this variation is known as the spatial fading pattern.

Considerable efforts have been devoted to the problem of relating fading patterns to properties of the glacier. Harrison² uses filter functions and relates radio echo fading patterns to the geometry of the reflecting bed, for certain categories of bed. He is able to generate realistic fading patterns by computer simulation experiments restricted to the vertical and one horizontal dimension in which the echo sounder moves horizontally, irradiating a randomly generated line with pulses of circular waves. Berry³, with rather more generality, develops Kirchhoff diffraction theory to apply to radio echo sounding and obtains relationships between statistical parameters of the bed and of the fading pattern (unpublished work). Nye, Kyte and Threlfall⁴, using an ultrasonic model echo sounder, find details of the fading pattern which vary appreciably when the echo sounder is moved horizontally by distances much smaller than a wavelength, but which are approximately stable with respect to small changes in the radio frequency, the bandwidth or the vertical position of the echo sounder. So the fading pattern can be regarded as a stable, finely-structured frame of reference fixed with respect to the glacier bed and Nye, Kyte and Threlfall suggest measuring the horizontal movement of a glacier surface relative to this frame of reference.

Here I describe field experiments in which the daily displacement of a site on the Fleming Glacier, Antarctic Peninsula

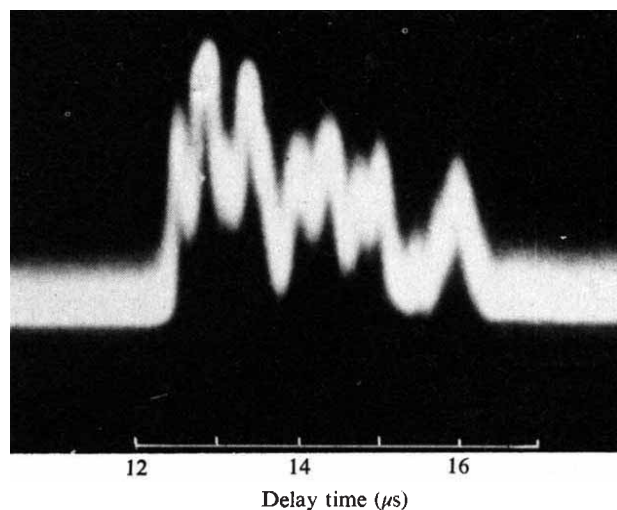


Fig. 1 A typical radio echo, rectified and with the carrier wave smoothed out. This echo was reflected from a rough glacier bed at a depth of 1,090 m. The transmitted pulse was 0.3 μ s long, the echo is 4.0 μ s long.

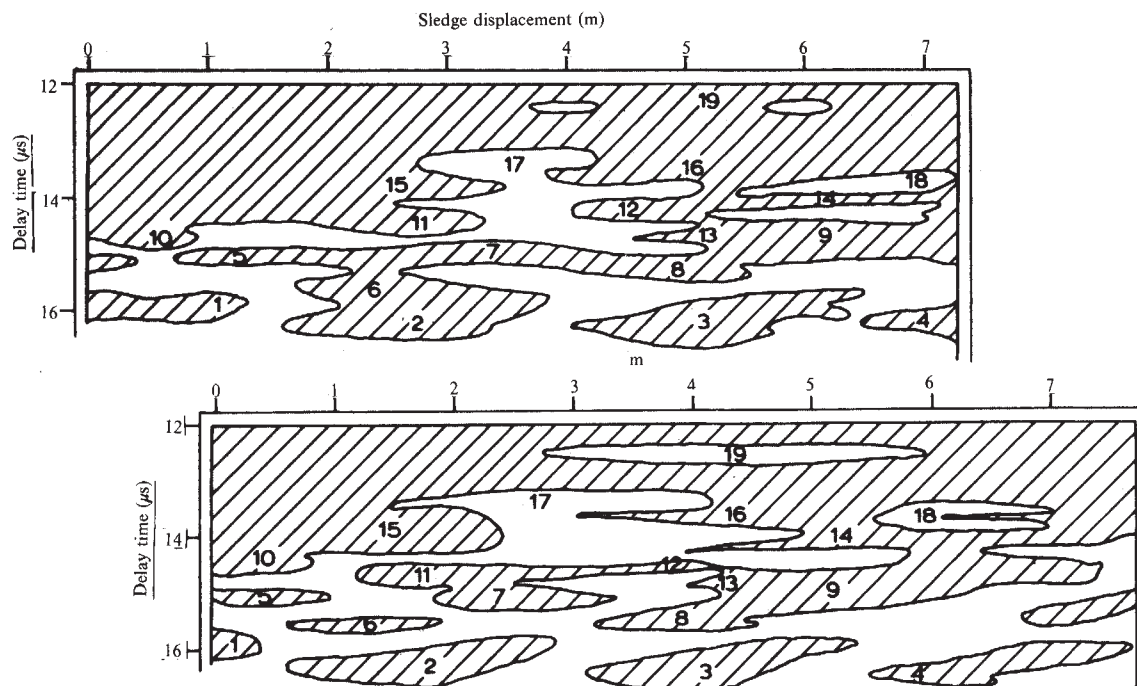


Fig. 2 Radio echo fading patterns obtained at 1106 GMT on January 28, 1972 (upper figure), and at 1242 GMT on January 31, 1972 (lower figure) along a line bearing 267° from a marker fixed in the snow. The data were derived from records of the type shown in Fig. 1, photographed at 25 cm intervals along the line. Hatched areas show where the echo strength is high. Pairs of numbers indicate corresponding features in the two records. The site was displaced by approximately 1 m in 3 days.

($69^\circ 30' S$, $66^\circ 16' W$), was measured by the radio echo technique. The results are compared with a value obtained by conventional optical surveying techniques.

A Scott Polar Research Institute Mark IV radio echo sounder⁵ was made available for this research by the British Antarctic Survey. The instrument transmits, at 40 μs intervals, pulses 0.3 μs long each containing ten cycles of 35 MHz radio waves. The radio wavelength in ice is 5 m.

Initially the apparatus incorporated a gating system designed to plot the fading pattern automatically and precisely. Unfortunately it could not be used because unexpected problems arose in the field; instead fading patterns were recorded photographically. This was a successful expedient but did not permit full use of the potential precision of the radio echo sounding technique.

C. W. M. Swinbank suggested that the Fleming Glacier, Antarctic Peninsula, would provide a suitable site for the experiment because it is a deep, cold glacier, and probably fast-moving. Airborne visual and radio echo observations show that in the vicinity of $69^\circ 30' S$, $66^\circ 16' W$ the ice is 1,090 m thick, the glacier surface is smooth and crevasse-free and a strong fading pattern is present. This site was occupied once during January 1972; a second visit planned for February 1972 was cancelled because of an engine failure in the support aircraft. The experiment described here was completed during the single visit.

Eight lines each 7.5 m long and forming a fan shaped pattern were surveyed. The fading pattern along each line was recorded daily from January 28 to 31, 1972 (Fig. 2). Fading patterns taken on successive days along a given line are similar, but are displaced upstream relative to markers in the ice, presumably because of downstream movement of the glacier. (Other minor differences between comparable records arise from limitations in the recording and plotting procedures and from glacier movement not parallel to the surveyed line. There is no evidence that the fading pattern is unstable with time.) Corresponding features in comparable fading patterns were measured (some personal judgment was necessary in making precise comparisons at this stage) and the component of glacier velocity along each line calculated (Fig. 3). These

components should lie on a circle whose diameter represents the true glacier velocity. A least squares analysis performed on a computer gives the value of the glacier velocity as 38 ± 3 cm/day along $260^\circ \pm 10^\circ$. In Fig. 3 I show the 95% confidence region within which the true velocity lies. A correction of +2 cm/day has been made to allow for an observed systematic stretching of a marked string used in the experiment. Other systematic errors are unlikely to exceed a few cm/day. Random errors in controlling the position of the sledge and in measuring the positions of features in the fading patterns probably contribute equally to the error in the final result.

Although the site was visited only once and the recording system lacked precision, the glacier displacement was measured

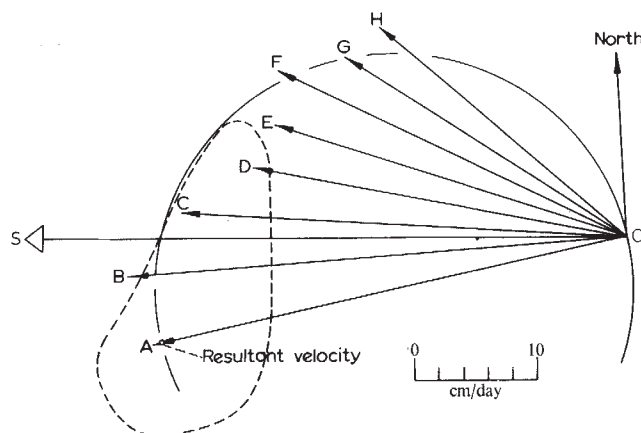


Fig. 3 The velocity of the Fleming Glacier, Antarctic Peninsula, $69^\circ 30' S$, $66^\circ 16' W$. Vectors OA to OH represent radio echo measurements of velocity components; OS represents the velocity measured by conventional optical surveying techniques. The circle is shown which best fits the radio echo results; its diameter corresponds to a glacier velocity of 38 cm/day along 260° . Dashes outline a region within which the true velocity is expected to lie, with 95% confidence.

with striking precision to approximately one hundredth of a radio wavelength.

Between February 22 and 26, 1972, C. W. M. Swinbank used conventional optical surveying techniques to measure the glacier velocity. He finds the value 46 ± 5 cm/day along $273^\circ \pm 10^\circ$ (personal communication) which agrees satisfactorily with the value obtained from radio echo sounding.

The fading pattern at a particular time τ after the start of the echo has a well-defined periodic length L measured along the sledge track. Berry (unpublished; see also refs. 2 and 6) shows that L is statistically independent of details of roughness of the glacier bed and is given by the expression

$$L = \frac{\lambda(2h + v\bar{\tau})}{2\sqrt{(2v\tau(4h + v\tau))}}$$

where h is the ice thickness, v the velocity and λ the wavelength of radio waves in ice; $\bar{\tau}$ defined by Berry differs negligibly from τ in the present application. Measurements of L made at the Fleming Glacier agree well with the above expression (Fig. 4).

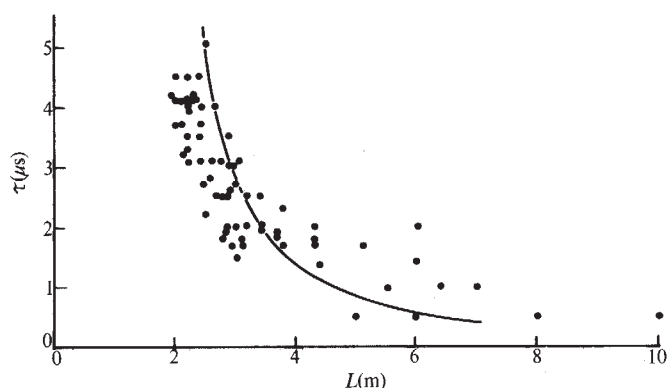


Fig. 4 Measurements of the periodic length L of the fading pattern of radio echoes as a function of τ the time delay after the start of the echo. The expression for L given in the text fits the data fairly satisfactorily. Measurements of L at large τ are slightly less than predicted probably because the radio echo aerial is not an isotropic radiator.

The best estimate of ice velocity at a given site should be obtained from measurements on the fading pattern at a particular delay time chosen as a compromise between sufficiently fine structure in the fading pattern and a large enough signal to noise ratio. This ratio can only be found by observation at the site because it depends on the performance of the echo sounder, the thickness, temperature and composition of the ice and on the roughness and reflectivity of the bed.

Further research into the technique described here is being pursued. The speed or precision of the experiment should be improved by moving the aerial along a calibrated track and by refining the method of recording radio echoes. More precise measurement of the direction of glacier flow may be possible using a different site geometry.

The radio echo technique is a comparatively cheap, simple and rapid way of measuring movement in polar ice masses, particularly in regions where no rock outcrops exist to provide visible fixed points.

Professor J. F. Nye suggested and guided the project. Dr C. W. M. Swinbank, British Antarctic Survey, provided equipment and was closely associated with the field work. Mr L. Wallis, University of Bristol, designed and built the gating system and Mr P. Burton, British Antarctic Survey, helped with the field work.

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- ¹ Bailey, J. T., Evans, S., and Robin, G. de Q., *Nature*, **204**, 420 (1964).
- ² Harrison, C., thesis, Univ. of Cambridge (1972).
- ³ Berry, M. V., *J. Phys. A. Gen. Phys.*, **5**, 272 (1972).
- ⁴ Nye, J. F., Kyte, R. G., and Threlfall, D. C., *J. Glaciology* (in the press).
- ⁵ Evans, S., and Smith, B. M. E., *J. Sci. Inst. (J. of Phys., E)*, **2**, 131 (1969).
- ⁶ Robin, G. de Q., Evans, S., and Bailey, J. T., *Phil. Trans. Roy. Soc., A*, **265**, 437 (1969).

Strengthening of Carbon Fibres by Fast Neutron Irradiation

To assess the effect of fast neutron irradiation on its structure and mechanical properties, a polyacrylonitrile (PAN) based fibre, manufactured by Rolls Royce Limited, was irradiated in the test facilities of the WR1 organic cooled nuclear reactor at temperatures in the range 400° – 700° C. Mechanical tests were made at room temperature on the fibres before and after irradiation using a Tecam microtensile test machine¹ and a gauge length of 1 cm. Fibre structure was studied by conventional X-ray diffraction techniques which have been described elsewhere². Fibre densities were measured by a gradient technique, the gradient components being carbon tetrachloride and tetrabromoethane.

In the unirradiated condition the fibre exhibited an average fracture strength (σ_f) of 2.86 GNm^{-2} and a Young's modulus (E) of 215 GNm^{-2} , properties typical for a PAN-based fibre heat treated to about $1,100^\circ \text{ C}^3$. The recorded average values of σ_f and E after several irradiation treatments are summarized in Table 1 together with appropriate test number and standard deviation.

Table 1 Influence of Fast Neutron Irradiation on the Mechanical Properties of PAN Based Carbon Fibre

Irradiation temp. $^\circ \text{C}$	Fluence ($E > 0.18 \text{ MeV}$) n cm^{-2}	Fracture strength, σ_f , GNm^{-2}	Young's modulus, E , GNm^{-2}
Unirradiated		$n^* = 80$ $\bar{x}^\dagger = 2.86$ $s^\ddagger = 0.67$	$n = 62$ $\bar{x} = 215$ $s = 19$
420 ± 20	4×10^{17}	$n = 37$ $\bar{x} = 3.21$ $s = 0.98$	$n = 34$ $\bar{x} = 231$ $s = 28$
500 ± 20	4×10^{17}	$n = 40$ $\bar{x} = 2.24$ $s = 0.68$	$n = 40$ $\bar{x} = 191$ $s = 19$
550 ± 10	3.6×10^{20}	$n = 40$ $\bar{x} = 3.42$ $s = 0.79$	$n = 40$ $\bar{x} = 237$ $s = 19$
550 ± 10	6.6×10^{20}	$n = 40$ $\bar{x} = 4.04$ $s = 1.01$	$n = 40$ $\bar{x} = 248$ $s = 19$
665 ± 10	5.4×10^{20}	$n = 40$ $\bar{x} = 3.37$ $s = 0.99$	$n = 40$ $\bar{x} = 252$ $s = 23$

* n = number of tests made.

$\dagger \bar{x}$ = average value.

$\ddagger s$ = standard deviation.

Irradiation at a temperature of $420^\circ \pm 20^\circ \text{ C}$ to a fluence (total neutron dose) of $4 \times 10^{17} \text{ n cm}^{-2}$ ($E > 0.18 \text{ MeV}$) produced an increase in σ_f of 12% and in E of 7%. Similar small increases have been reported by other workers after irradiation to similar fluences at temperatures below 80° C^{4-7} . Allen, Cooper and Mayer⁴⁻⁶ attribute the property changes to the pinning of dislocations by irradiation-induced interstitial atoms.

Irradiation at $500^\circ \pm 20^\circ \text{ C}$ to a fluence of $4 \times 10^{17} \text{ n cm}^{-2}$, however, produced a significant decrease in both σ_f and E of 22% and 11% respectively. Decreases in strength and modulus

have been reported^{2,8} for a higher modulus PAN based fibre and, in this instance, the changes were attributed to irradiation-induced crack or void formation in the fibres.

Irradiation at still higher temperatures of $550^\circ \pm 10^\circ$ and $665^\circ \pm 10^\circ$ C to higher fluences resulted in increases of σ_f and E which were even greater than those found after irradiation at 420° C to the lower fluence. The greatest change in properties so far recorded occurred after irradiation at $550^\circ \pm 10^\circ$ C to a fluence of 6.6×10^{20} n cm⁻² when σ_f showed an increase of $\sim 40\%$ to 4.04 GNm⁻² and E increased by $\sim 12\%$ to 248 GNm⁻². A further interesting result of this treatment is that "strain to fracture" increased from 1.2% in the unirradiated fibre to 1.6% after irradiation.

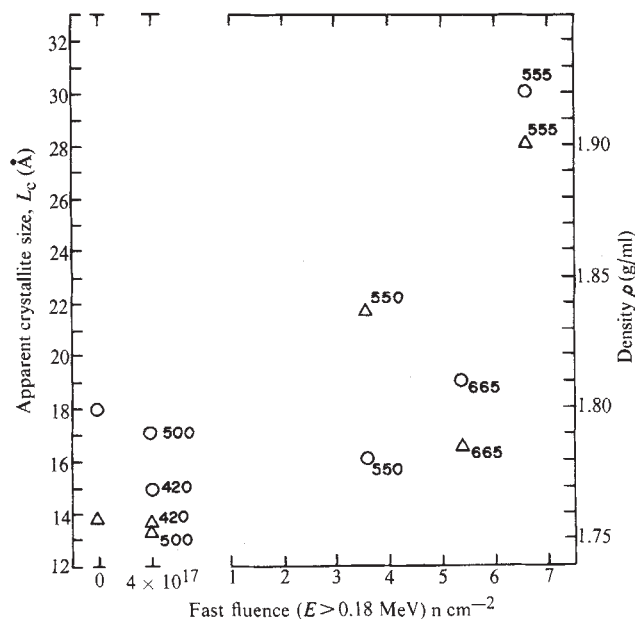


Fig. 1 Variation of apparent crystallite size (O), L_c , and density, ρ (Δ), with fast fluence. Irradiation temperatures are shown next to the experimental points.

Changes in fibre density and apparent crystallite size, L_c , are shown in Fig. 1. It is interesting to note that the maximum and minimum recorded values of density coincide with the maximum and minimum values of σ_f and E . Similarly, in the case of the largest change in mechanical properties (after irradiation to 6.6×10^{20} n cm⁻² at $550^\circ \pm 10^\circ$ C) the L_c parameter also shows a marked increase. This observation appears to be in agreement with the behaviour of higher modulus fibres where improved mechanical properties are observed together with an apparent recrystallization process during high temperature irradiation (our unpublished work).

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- ¹ Marsh, D. M., *J. Sci. Instr.*, **38**, 229 (1961).
- ² Jones, B. F., and Peggs, I. D., *J. Nucl. Mater.*, **40**, 1591 (1971).
- ³ Johnson, J. W., *Appl. Polym. Symp.*, **9**, 229 (1969).
- ⁴ Allen, S., Cooper, G. A., and Mayer, R. M., *Nature*, **224**, 684 (1969).
- ⁵ Allen, S., Cooper, G. A., and Mayer, R. M., *Third Intern. Conf. on Industrial Carbon and Graphite* (Society of Chemical Industry, London, 1970).
- ⁶ Cooper, G. A., and Mayer, R. M., *J. Mater. Sci.*, **6**, 60 (1971).
- ⁷ Bullock, R. E., *Radiation Effects*, **2**, 107 (1971).
- ⁸ Jones, B. F., *Tenth Biennial Conf. on Carbon, Bethlehem, Pennsylvania*, Summary of Papers, 190 (1971).

Field Emission from Carbon Fibres: A New Electron Source

IN certain electron beam devices, field electron emitting sources possess distinct advantages over thermionic emitters¹. Much effort has been expended to exploit these advantages in instruments such as scanning electron microscopes², microwave amplifiers^{1,3}, and X-ray generators^{1,4}. The preferred emitter material in nearly all these devices has been tungsten, which operates only under ultra high vacuum conditions; it is primarily for this reason that field electron emitters have not been widely adopted commercially. Consequently attempts have been made to find materials which will operate in the region 10^{-6} to 10^{-8} torr⁵⁻⁷. As field electron emitters silicon carbide "whiskers" were less sensitive to vacuum conditions than tungsten⁸, but a number of practical difficulties—the material varied considerably from sample to sample, it was not easy to make a reliable ohmic contact to the crystal and the etching technique (similar to that of Smith⁹) was somewhat variable in its results—made reproducible operation difficult.

A carbon filament possesses the properties required of a satisfactory material. The fibres selected¹⁰, approximately 7 μ in diameter, were readily available and had well characterized electrical and mechanical properties, an ohmic contact can be readily made using 'Aquadag' and the tip can be easily and reproducibly shaped by a controlled corona discharge in air.

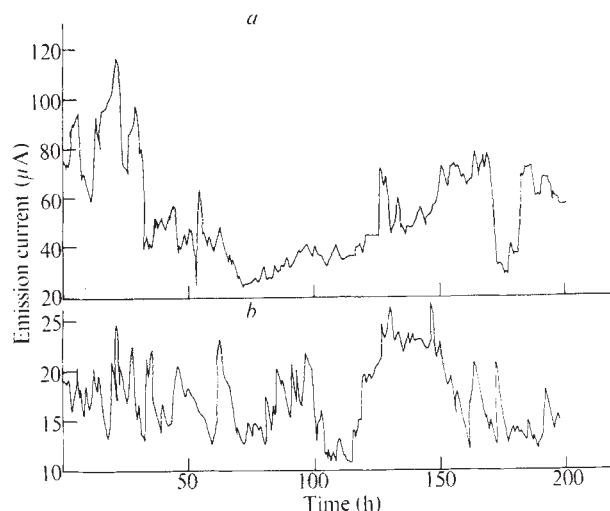


Fig. 1 Variation of current with time for two different fixed potentials. *a*, Approximately 1.5 kV; *b*, approximately 0.8 kV.

The fibres were found to emit electrons in a vacuum of 10^{-3} torr but under these conditions emission was very noisy and the lifetime short for currents greater than 10 μ A. The properties were studied at pressures in the range 10^{-7} to 10^{-8} torr and on those fibres which emitted at low voltages (typically 1 μ A at 500 V). Fig. 1 shows the variation of emission current with time. For 10 μ A nominal emission current the lifetime of the fibres exceeded 2,400 h (the duration of the experiment); for 100 μ A, 500 h; and for 200 μ A, 24 h. The current can be seen occasionally to vary from hour to hour, but no explanation of this very low frequency noise is as yet available.

Noise in the range 20 Hz to 10 KHz was examined using a Tektronix Type 1L5 spectrum analyser. The noise diminished with increasing frequency and became difficult to measure above about 1,000 Hz. A portion of the spectrum is shown in Fig. 2. We have established that there is considerable correlation of the low frequency noise in different parts of the electron beam and hence it should be possible to use a portion of the beam for the purpose of stabilizing emission from the source

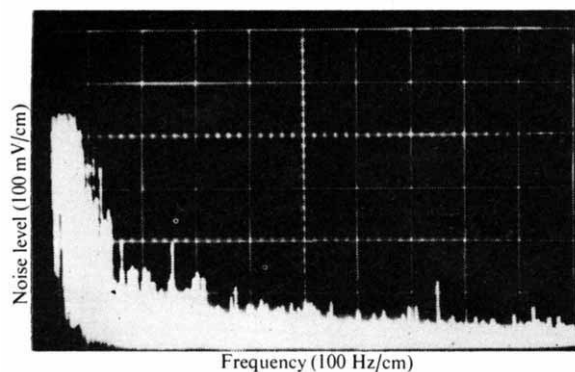


Fig. 2 Noise spectrum as displayed by Tektronix Type 1L5 spectrum analyser; centre frequency 500 Hz; dispersion 100 Hz; resolution 10 Hz; spectrum scanned four times at a rate of 50 s per scan.

for those applications in which this type of noise would be unacceptable.

The current emitted from the fibres varies approximately exponentially with applied voltage and the electron beam was usually confined within a cone angle of 60° . This angle could be as small as 10° when the electric field near the fibre was modified by reducing the distance of its tip from the flat mounting plate. It was then found to be necessary to increase the applied voltage by as much as a factor of ten in order to maintain the emission current at the same level. The sharper tips, which gave an emission current of $1 \mu\text{A}$ at 500 V or less, broke down after running for a few minutes at $400 \mu\text{A}$, corresponding to a current density of greater than 10^6 A cm^{-2} . Continuous operation at 10^{-8} torr could be obtained for current densities estimated to be about 10^5 A cm^{-2} .

To test the practicability of carbon fibres as a source of electrons a very simple scanning electron microscope based on the electrostatic lens system of Crewe *et al.*¹¹ was constructed, with the fibre as the emitter. An initial resolution of better than 0.2μ has been demonstrated with a system pressure between 10^{-7} and 10^{-8} torr.

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- ¹ Dyke, W. P., and Dolan, W. W., *Adv. Elect. Electron Phys.*, **8**, 89 (1956).
- ² Crewe, A. V., Isaacson, M., and Johnson, D., *Rev. Sci. Instr.*, **40**, 241 (1969).
- ³ Charbonnier, F. M., Barbour, J. P., Garrett, L. F., and Dyke, W. P., *Proc. IEEE*, **51**, 991 (1963).
- ⁴ Olin, T., and Carlsson, C., *Radiolge*, **2**, 451 (1962).
- ⁵ Windsor, E. E., *Proc. IEE*, **116**, 3, 348 (1969).
- ⁶ Elinson, M. J., and Kudintseva, G. A., *Rad. Eng. Elect. Phys.*, **7**, 1417 (1962).
- ⁷ Utsumi, T., and Dalman, G., *Appl. Phys. Lett.*, **11**, 397 (1967).
- ⁸ Baker, F. S., *Nature*, **225**, 539 (1970).
- ⁹ Smith, D., *J. Sci. Instr. E*, **2**, 106 (1969).
- ¹⁰ British Patent No. 1,110,791.
- ¹¹ Crewe, A. V., Eggenberger, D. N., Wall, J., and Welter, L. M., *Rev. Sci. Instr.*, **39**, 576 (1968).

Nucleation of Voids in Irradiated Stainless Steel

AUSTENITIC steels are primary materials for use as fuel cladding and core structural components in high-flux fast breeder reactors. Considerable attention has recently been focused^{1,2}

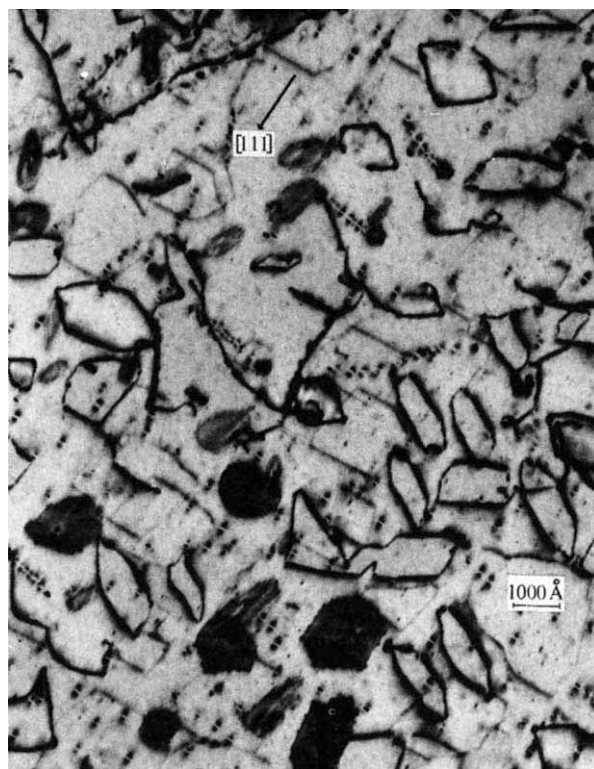


Fig. 1 Frank loops, diamond loops and void nuclei in Type 316 stainless steel irradiated in the JEM-1000 high voltage electron microscope at 500°C . The damage level at this point is 0.08 d.p.a. Imaged with a systematic $\{111\}$ diffraction condition and recorded at 1,000 kV, 500°C .

on the phenomenon of void formation—three-dimensional clusters of lattice vacancies; the retention of vacancies in the form of such stable secondary defects results in a significant volume expansion of the void-containing material. Reactor core design is complicated by this swelling phenomenon, and it is desirable to eliminate or minimize the effect. The study of void formation in austenitic steels by transmission electron microscopy has previously been limited to studies in the void growth regime. With the availability of high voltage electron microscopes, the very early stages of void formation can be studied by direct observation of specimens while under irradiation in the electron microscope. Using this technique, we have been able to observe the nucleation and growth of voids in AISI Type 316 stainless steel.

A Type 316 stainless steel specimen was solution-annealed at $1,200^\circ \text{C}$, water-quenched and thinned by conventional electrochemical techniques. The specimen was then irradiated at 500°C in the 'JEM-1000' electron microscope, operating at an accelerating voltage of 1,000 kV. The electron flux at the specimen position was $1.0 \times 10^{19} \text{ e cm}^{-2} \text{ s}^{-1}$; the same area of the specimen was photographed at 5-min intervals. Defects were found to be present after the first 5-min period of electron irradiation. These defects subsequently evolved into three distinct types: Frank loops with Burgers vector $a/3\langle 111 \rangle$, on $\{111\}$ s; diamond loops with Burgers vector $a/2\langle 110 \rangle$, on $\{110\}$ s; and void nuclei. The defect microstructure is illustrated in Fig. 1. The void nuclei are characterized by the familiar Ashby-Brown³ strain contrast with the line of no contrast normal to $(n)\vec{g}$. These defects were initially presumed to be small, unresolved dislocation loops; during the course of the experiment, however, it was found that these defects did not grow, while the Frank loops and diamond loops grew at quite large rates. Ultimately, resolvable voids were observed at a damage level of approximately 0.11 d.p.a. (displacements per atom); it was found by comparison of successive photographs in the series that each

void could be traced back to the very smallest void nucleus. Not all void nuclei, however, grew into resolvable voids. Void nucleation was also found to be confined to the very early stages of irradiation.

In addition to the evidence that the void nuclei are observed to grow to the point where their strain field disappears and octahedral voids are resolvable, the strain fields were also analysed under two-beam dynamic conditions at 200 kV. In this case it was found that the line of no contrast is always normal to the operating $\vec{g}$, as demonstrated with $\vec{g} = (111)$, $(\bar{2}20)$ and $(\bar{1}31)$. Analysis of the strain fields using the Ashby-Brown method³ confirmed the vacancy nature of the clusters. The smallest void nuclei observed were in the 12–15 Å diameter range, which amounts to a cluster content of some 80–160 vacancies. This cluster size is slightly in excess of the critical nucleus size of thirty-seven vacancies computed⁴ for austenitic steel at 500° C with a vacancy supersaturation of 10^4 and allowance for interstitial absorption at voids.

Our observations should be of value in assessing the swelling resistance of materials for fast breeder reactor applications. Once favourable void nucleation conditions can be confirmed by experiment and adjustments to nucleation theories made, it will be possible to adjust materials parameters to suppress void nucleation.

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¹ *Proc. Europ. Conf. Voids Formed by Irradiation of Reactor Materials* (edit. by Pugh, S. F., Loretto, M. H., and Norris, D. I. R.) (Brit. Nucl. Energy Soc., 1971).

² *Proc. Intern. Conf. Radiation Induced Voids in Metals*, SUNY, Albany, New York, June 1971 (to be published).

³ Ashby, M. F., and Brown, L. M., *Phil. Mag.*, **8**, 1649 (1963).

⁴ Powell, R. W., and Russell, K. C., *Radiat. Effects*, **12**, 127 (1972).

Effect of Voids on Angular Correlation of Positron Annihilation Photons in Molybdenum

POSITRON annihilation investigations of defects in crystals have shown that for sufficiently high defect concentrations (typically above about 10^{-6}) all positrons become trapped in the defects before annihilation, thus changing the characteristics of the annihilation process. For example, trapping of positrons may result in the increase in the positron lifetime, a narrowing of the 2- γ angular correlation distribution, and a reduction in the Doppler broadening of the annihilation line. Vacancies in metals^{1,2}, deformation effects in metals³, and defects (F-centres or cation vacancies) in ionic crystals⁴ have all now been studied by this technique. The trapping of positronium (Ps) in defects in quartz⁵ and ice⁶ has also been investigated. Here we report the study of another crystal defect, the void, a small vacancy of diameter few tens of Ångströms. In practice voids may contain gas atoms and may be disturbed either in a random fashion or arranged in a macro lattice⁷.

Voids were produced by a fast-neutron irradiation of molybdenum, 0.5% Ti, 0.07% Zr, at about 3.10^{22} n/cm² (>1 MeV) in the Dounreay high flux reactor. During the irradiation the temperature of the sample was $650^\circ \text{C} \pm 30^\circ \text{C}$. Voids produced a mean diameter of 35–40 Å, arranged on a macroscopic lattice with crystallographic directions parallel to those of the host lattice of approximately 340 Å. A polycrystal sample, annealed at 1,100° C for 6 h and finally cleaned by etching, was used as a standard.

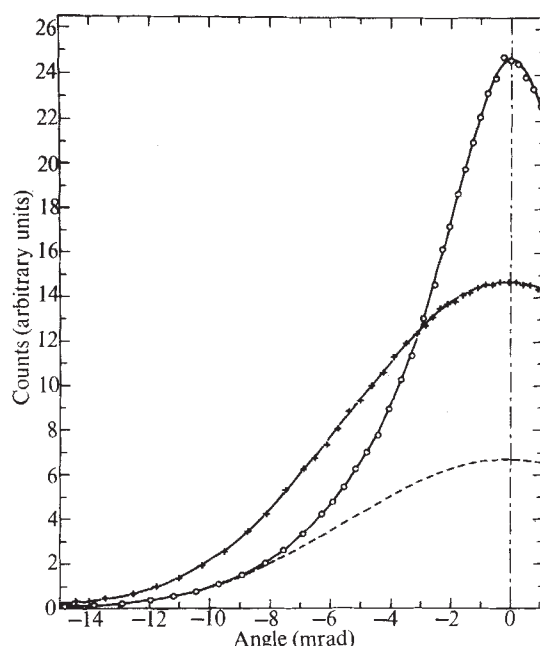


Fig. 1 Angular correlation curves for polycrystalline molybdenum containing voids and for annealed polycrystalline molybdenum. The two curves are normalized to equal areas. The statistical counting uncertainties in the top of the curves are about $\pm 0.5\%$. ○—○, Polycrystal (voids); ×—×, polycrystal; ---, 0.46 $\times$ polycrystal.

Fig. 1 shows a 2- γ angular correlation curve for polycrystalline molybdenum containing voids, and a curve for annealed polycrystalline molybdenum. A standard linear-slit angular correlation configuration⁸ was used. The detectors covered a solid angle of about 0.48×178 mrad as seen from the sample. The angular resolution of the setup was around 0.6 mrad. The curves are corrected for a small ($\approx 0.2\%$ of the counts at the maximum) random-coincidence background. We used an external source of approximately 15 mCi $^{22}\text{NaCl}$, and the measurements were performed at room temperature.

The effect of the voids (Fig. 1) was confirmed by a measurement of the Doppler broadening of the annihilation line, using an 'Ortec Ge(Li)' true coaxial detector. The full width at half maximum (FWHM) of the 1.33 MeV-line of ^{60}Co was 1.80 keV corresponding to an angular correlation resolution of about 5.2 mrad. The void sample described below gave a curve of $\text{FWHM} \approx 2.21 \pm 0.11$ keV which corresponds to an angular correlation curve $\text{FWHM} \approx 8.5 \pm 0.4$ mrad after a rough correction for the finite resolution of the detector. For a different polycrystalline sample $\text{FWHM} \approx 2.88 \pm 0.14$ keV and $\text{FWHM} \approx 11.1 \pm 0.6$ mrad respectively, we conclude therefore that the two techniques agree reasonably well.

Placing the samples in a magnetic field of 20 kG produced no significant change in Doppler broadening measurements. Similar magnetic quenching measurements on water and benzene (in which positronium (Ps) is formed) gave a decrease of $\Delta\text{FWHM} \approx 3.6\%$ and $\Delta\text{FWHM} \approx 5.6\%$ respectively in the width of the curves on application of a 20 kG magnetic field.

As shown in Fig. 1 the presence of the voids causes a very pronounced narrowing of the angular correlation curve. The annealed polycrystalline sample curve conforms to a Gaussian of FWHM 12.4 mrad whereas for the void sample the FWHM ≈ 6.1 mrad and the curve was non-Gaussian. McGurvey⁹ reports a Gaussian of FWHM 11.7 mrad for a similar specimen. The difference could be due to annealing treatments. Such narrowing of an angular correlation curve has not been observed previously for metals. Normally, trapping of positrons introduces only a 5–10% narrowing of the curves. As shown in Fig. 1 a "polycrystal" curve of 46% of the intensity of the normalized polycrystal and void curves fits well to the

tail of the void curve. Such a fit is probably fortuitous and might have been obtained whichever well-behaved "void" curve had been measured; it does not necessarily indicate that there actually was 46% annihilation in the bulk of the sample.

The fact that a magnetic field of 20 kG gives no effect shows that either no Ps-atoms are formed in the void or that Ps is formed, but all ortho-Ps are converted into para-Ps, possibly by the presence of O₂ molecules in the voids. A very short ($\lesssim 0.1$ ns) ortho-Ps lifetime in the voids would also mean that the magnetic quenching effect is too small to be detected⁸. In view of the absence of a magnetic effect, and because the voids only constitute 0.15% of the volume, we believe that no Ps is present in the voids although the data do not unambiguously exclude the possibility. Ps has never yet been observed in a metal.

The most reasonable explanation of the effects observed with the void specimen is that positrons are thermalized mainly in the bulk of the material. Some or all are then trapped in the voids, where they can probably be described by the wave function corresponding to the zero point energy. This wave function overlaps somewhat with the valence electron wave functions on the void surface. In the independent particle model the angular correlation setup measures a distribution which reflects the Fourier transform of the product of the positron and the electron wave function. The zero point energy wave function of the positron will only contribute a small part of the width of the curves because of the large size of the voids, and the angular correlation curves are probably mainly determined by the Fourier transform of those parts of the valence electron wave functions which overlap with the positron wave function within about 1 Å of the surface of the voids. Another less likely explanation is that the positron is trapped in some sort of surface layer in the void, as used by Gainotti and Ghezzi¹⁰ to explain lifetime spectra for germanium and silicon powders.

Clearly the effect of the voids cannot be interpreted unambiguously on the basis of these preliminary data. The positron techniques, however, seem to give much information on voids in metals when standard cases have been investigated and properly interpreted, and contribute to the solution of one of the most important material problems in fast neutron reactor research: the swelling and weakening of materials because of void formation.

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Correlation of Void Size and Positron Annihilation Characteristics in Neutron-irradiated Molybdenum

THE occurrence of voids induced by fast neutrons in metals is a matter of considerable concern because of the restrictions these defects can impose on the design of fast power reactors. Void formation is invariably accompanied by swelling and the concomitant threat of rupture of critical components. Technical interest in this problem is matched by scientific curiosity regarding the general principles of void formation and, in particular, the intriguing observation that the voids are sometimes arranged in a macroscopic lattice. At present progress in studies of these phenomena is slow because of the long irradiation time required to make voids observable by electron microscopy. Moreover, because that technique is destructive, it has not been possible to follow the evolution of voids in a single sample.

A new non-destructive technique for the study of crystal defects is under development which uses the positron as a probe to reveal properties of these imperfections. Atomic rearrangements near a defect can change both the local density of electrons and their momentum distribution. These effects lead respectively to changes in the lifetime of an injected positron before it annihilates with an electron, and the angular correlation of the resultant annihilation photons. The technique has been used for probing vacancies¹ and dislocations², and the dependence of annihilation characteristics on defect concentration have been interpreted by simple trapping models^{3,4}. Here we report preliminary results of an investigation of positron behaviour in neutron-irradiated molybdenum containing voids of diameter 30–40 Å.

All specimens had been arc-cast and zone-refined to a purity of 4 p.p.m. Neutron irradiation was carried out in the Dounreay high flux reactor; the doses and irradiation temperatures are shown in Table 1, where we also show the corresponding void sizes and concentrations, as established by electron microscopy of specimens in the same irradiation batch. The voids were arranged in a macroscopic lattice whose direction vectors were parallel to those of the host lattice⁵. It was not possible in the present experiments to detect any specific influence of this regular arrangement, because we made no comparison with specimens containing random distributions of voids. The regularity of the void lattice gave a well defined void density and size. A standard annealed molybdenum specimen, and a specimen that was deformed 50% by rolling at room temperature, were also investigated. The latter was used in a crude check for the influence of monovacancies on the positron annihilation parameters. Monovacancies in molybdenum are immobile at room temperature.

We made lifetime determinations using an orthodox fast-slow system with constant fraction discrimination. The resolution function of the instrument is shown in Fig. 1a. In a typical defect-free metal the lifetime spectrum is a simple exponential with a mean lifetime of about 200 ps. This time is, however, similar to the resolving time of the instrument used to measure the distribution and hence the measured spectrum is severely distorted. Fig. 1b shows the time spectrum obtained with the annealed reference material which has a lifetime of 146 ± 3 ps. The lifetime spectra for the void specimens (see Figs. 1c and 1d) are dramatically different from that obtained with the reference, and the corresponding mean lifetime (see Table 1) are the highest ever observed in a metal. Background counts have been subtracted from each of the spectra in Fig. 1 and, in addition, a small component of 2% total intensity and 500 ps mean lifetime, attributed to source annihilations, has been removed. Using the same source and counting rates as in the Mo measurements the system yields a value of 166 ± 3 ps for annealed high-purity Al.

In so far as voids can be regarded as "supervacancies", it is interesting to compare the behaviour of positrons in these large

¹ McKee, B. T. A., Triftshäuser, W., and Stewart, A. T., *Phys. Rev. Lett.*, **28**, 358 (1972).

² Cotterill, R. M. J., Petersen, K., Trumphy, G., and Träff, J., *J. Phys.*, **F2**, 459 (1972).

³ Hautojärvi, P., Tamminen, A., and Jauho, P., *Phys. Rev. Lett.*, **24**, 459 (1970).

⁴ Mallard, W. C., and Hsu, F. H., *Phys. Lett.*, **38**, A, 164 (1972).

⁵ Coussot, C., and Paulin, R., *J. Appl. Phys.*, **43**, 1325 (1972).

⁶ Eldrup, M., Mogensen, O., and Trumphy, G., *J. Chem. Phys.* (in the press).

⁷ Eyre, B. L., and Evans, J. H., in *Voids Formed by Irradiation of Reactor Materials* (edit. by Pugh, S. F., Loretto, M. H., and Norris, D. I. R.), 323 (British Nuclear Energy Society, 1971).

⁸ Goldanskii, V. J., *Atom. Energ. Rev.*, **6**, 1 (IAEA, Vienna, 1968).

⁹ McGervey, J. D., in *Positron Annihilation* (edit. by Stewart, A. T., and Roellig, L.), 305 (Academic Press, New York, 1967).

¹⁰ Gainotti, A., and Ghezzi, C., *J. Phys.*, **C5**, 779 (1972).

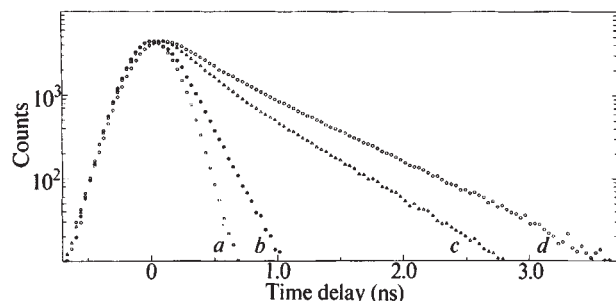


Fig. 1 Annihilation time spectra observed in specimens of molybdenum of 4 p.p.m. total initial impurity. *a*, Instrument resolution function. *b*, Annealed polycrystalline specimen. *c*, Void specimen No. 9. *d*, Void specimen No. 15. Background and source components have been deducted from the last three curves.

defects with that observed in a monovacancy. In a typical metal the maximum lifetime increase induced by vacancies is about 20% and the largest recorded change is 45% in copper. Equilibrium vacancy measurements have not been reported for molybdenum using the positron technique. Cold-rolling also produces vacancies, however, and the results obtained with the deformed specimen (see Table 1) indicate a lifetime increase of 22% because of these defects. In the present experiments it is tempting to assign the observed long lifetime to trapping in voids of the nominal diameter quoted in Table 1. But because there was a distribution of void sizes in each irradiated specimen and because there are only three points on the curve (monovacancies, 30 Å voids, and 40 Å voids) it is premature to generalize on the correlation between void size and lifetime.

We also examined the void specimens by 2-photon angular correlation, to obtain information on the momentum distribution of the annihilating electron-positron pairs. In the defect-free metal most of the momentum is provided by the electron since typical positron energies at the time of annihilation are about 0.1 eV. When positrons are trapped in defects of atomic dimensions, such as vacancies or edge dislocations, they are forced to increase their energy, as demanded by the uncertainty principle. Experiments show, however, that the overall influence of trapping is a reduction in the momentum of the centre of mass, primarily because the trapped positron is less likely to annihilate with the faster core electrons. The usual net effect is a reduction in the width of the energy spectrum by 5 to 10% with no great difference between the influence of vacancies and edge dislocations. The pronounced effect of voids upon the angular correlation curve, which has been reported by Mogensen *et al.*⁶, was also observed in the present study. Further, we found that the narrowing depends on void diameter or, at least, on the void size distribution (see Table 1 and Fig. 2). The reduction in width of the angular distribution by deformation was about 12%, a slightly larger effect than has been observed in other metals.

Very long lifetimes in condensed matter have, in the past, been associated with positronium formation. Until now experiments have supported the theoretical result that this cannot happen in a metal. The massive effects reported here force us to question whether this conclusion is valid for the case of metals containing voids. A check for positronium formation was made by measuring the angular correlation at magnetic field strengths of zero and 20 kG. No difference and thus no magnetic quenching were observed. Such a negative result sets an upper limit on the degree of positronium formation. Assuming that it implies a total absence of the singlet-triplet conversion, and that the angular correlation curve caused by 2-photon annihilation from the triplet state would be twice as broad as for the singlet, we find that the positronium-positron intensity ratio is less than 3%.

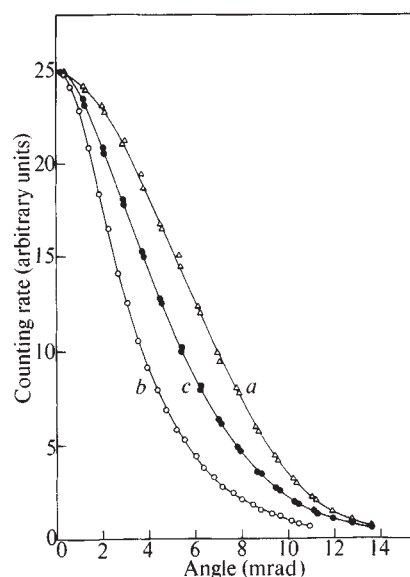


Fig. 2 Angular correlation curves observed in the high-purity molybdenum specimens using a resolution of 1.8 mrad. *a*, Annealed polycrystalline specimen. *b*, Void specimen No. 9. *c*, Void specimen No. 15. ○, 455° C; ●, 680° C; △, unirradiated.

The detailed interpretation of the data presented here must await further information on positron behaviour in metal voids. It seems to be established that positrons can be trapped in voids, where they can exist with greatly reduced electron overlap, and this qualitatively explains the long lifetime component and its increase with void size. The fact that the angular correlation is narrower for the small voids than for the larger ones is quite unexpected. It is a striking reminder of the fact that positron lifetimes and angular correlations measure two

Table 1 Irradiation History, Void Distribution and Annihilation Characteristics of the Molybdenum Specimens

Specimen	Irradiation		Void diameter (Å)			Void density cm ⁻³	Annihilation properties	
	Fluence n/cm ²	Temp. °C	Mode	Min	Max		Longest lifetime (ps)	Ang. corr. FWHM (mrad)
Annealed	0	—	—	—	—	0	146 ± 3	12.3 ± 0.15
Deformed (50%)	0	—	—	—	—	—	177 ± 3	10.9 ± 0.15
Voids No. 9	1.7 × 10 ²²	465	32	10	65	2 to 5 × 10 ¹⁷	467 ± 6	6.1 ± 0.15
Voids No. 15	1.7 × 10 ²²	680	40	10	100	10 ¹⁶ to 10 ¹⁷	595 ± 8	9.2 ± 0.15

The time spectra for both of the void specimens show a curvature which implies a superposition of lifetimes. We could, following normal practice in metal defect studies, fit the spectra by a combination of two components with adjustable slopes and intensities. Such a procedure does indeed provide a good fit, but we question its physical significance since we could also fit the data by assuming a wide distribution of lifetimes; this latter procedure would be fully justified since it is known that the voids are not uniform size and there is a correlation of void size with lifetime. The lifetimes listed in the table are obtained by simple visual fits to the straight regions of the time spectra.

very different quantities, the electron density at the positron and the centre-of-mass momentum. The encouraging results reported here suggest that this non-destructive monitoring technique holds promise as a viable early warning system for impending rupture in reactor fuel cladding and other critical reactor components.

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- ¹ Mackenzie, I. K., Khoo, T. L., McDonald, A. B., and McKee, B. T. A., *Phys. Rev. Lett.*, **19**, 946 (1967).
- ² McKee, B. T. A., Bird, H. M. B., and Mackenzie, I. K., *Bull. Amer. Phys. Soc.*, **12**, 687 (1967).
- ³ Bergensen, B., and Stott, M. J., *Sol. State. Comm.*, **7**, 1203 (1969).
- ⁴ Connors, D. C., and West, R. N., *Phys. Lett.*, **30A**, 24 (1969).
- ⁵ Eyre, B. L., and Evans, J. H., *Proceedings of the British Nuclear Energy Society European Conference on Voids Formed by Irradiation of Reactor Materials* (Reading, 1971).
- ⁶ Mogensen, O., Petersen, K., Hudson, B., and Cotterill, R. M. J., *Nature* (in the press).

BIOLOGICAL SCIENCES

Protein Breakdown inhibited by Insulin to improve Heart Culture

EVEN in the best systems currently available for maintaining isolated hearts *in vitro*, progressive deterioration and death of the organs occur. To provide a convenient means for studying the factors that control long-term survival and function of isolated myocardium a method has recently been developed for maintaining spontaneously-beating hearts from late foetal mice in organ culture¹. The technique, which was developed from the general methods for culturing other organs used by Fell and her colleagues², enables function to be preserved for several days or weeks before death finally occurs^{1,3,4}.

Preliminary experiments have demonstrated that the constitution of the medium nourishing the organs is a major factor in determining survival time. Insulin is of special importance in this regard. When the hormone is added in high concentrations to the medium the duration of beating of the hearts is almost doubled³. The beneficial effect of insulin does not seem to be mediated simply by an increase in glucose availability to the cells, since the effect persists even in a medium of low glucose level, and since an increase in glucose uptake induced by high glucose levels in the medium has no beneficial action⁵. Insulin does not alter the ratio of glucose to fatty acid utilization in the cultured foetal hearts nor does it influence the concentrations of adenosine triphosphate and creatine phosphate (J. Karlsson and K. Wildenthal, unpublished data).

To test other mechanisms by which insulin might alter the ability of the heart to function *in vitro*, studies of protein and amino-acid balance were made in the cultured hearts. Total protein content of the hearts was measured by the Lowry technique⁶, 2–8 days after explantation. At all times and in all conditions tested the hearts were in a catabolic state, even in the presence of insulin. The rate of catabolism was significantly altered by the hormone, however. As shown in Fig. 1, hearts maintained in the absence of supplemental insulin lost an average of $11 \pm 0.5\%$ (s.e.m.) of their protein mass each

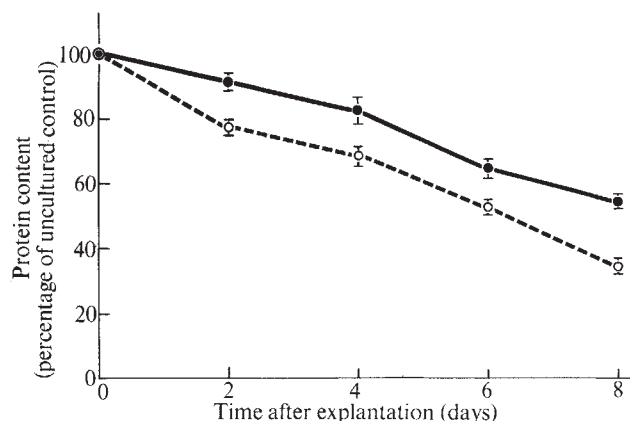


Fig. 1 Total protein content of intact hearts from 19–20 day foetal mice maintained in organ culture¹ in the presence (●—●) or absence (○---○) of supplemental insulin. The total protein content of each heart was expressed as a percentage of the protein content of hearts of matched litter mates before cultivation. Each point represents the mean of four hearts and the vertical bars represent $\pm$ one standard error of the mean. Hearts from matched litter mates were maintained in 'medium 199' (ref. 7) supplemented with 35% newborn calf serum, with or without 50 μ g/ml. of purified insulin. The atmosphere was 95% O₂ + 5% CO₂, and the temperature was 37.5° C.

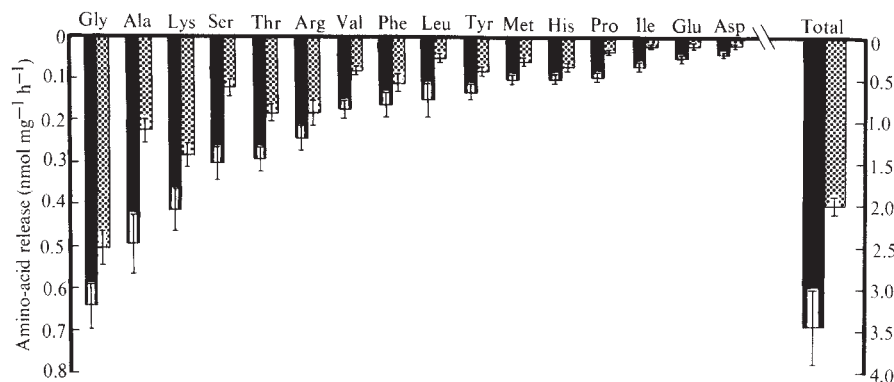
day. In hearts exposed to high concentrations of the hormone, protein loss was reduced to $6 \pm 0.4\%$ each day ($P < 0.001$). Significant differences between matched litter mates were apparent as early as 2 days after explantation.

The pattern of myocardial loss of individual amino-acids was analysed by maintaining the hearts in a chemically-defined amino-acid-free medium and measuring the total amount of each amino-acid released into the medium over a 3-day period. Measurements were made on a 'Beckman' amino-acid auto-analyser. Fig. 2 illustrates the results obtained from 9 experiments in which matched litter mates were compared. The release of each of the 16 amino-acids that were separated and measured was significantly reduced by insulin ($P < 0.01$). However, the degree to which insulin affected each individual compound varied widely. For example, there was consistently a selective conservation of alanine (release was $55 \pm 6.2\%$ less in the presence of insulin than in its absence), serine (release was $62 \pm 2.6\%$ less), valine ($55 \pm 4.6\%$ less), leucine ($63 \pm 4.8\%$), proline ($60 \pm 5.2\%$), and isoleucine ($69 \pm 4.9\%$), compared with glycine ($20 \pm 4.6\%$), lysine ($32 \pm 5.4\%$), arginine ($27 \pm 5.3\%$), phenylalanine ($32 \pm 6.1\%$), tyrosine ($35 \pm 3.7\%$), and histidine ($28 \pm 5.7\%$).

Efforts to establish common biochemical or metabolic features of those amino-acids that were especially affected by insulin have been unsuccessful. Thus, the group that was selectively altered included amino-acids, for example, valine, that are not transaminated or oxidized in myocardium and those such as alanine that can be transaminated and used for energy production. Also, amino-acids such as isoleucine whose cellular uptake into myocardium is not altered significantly by insulin could be affected in the present system to the same degree as those such as proline whose uptake is greatly enhanced by the hormone⁸. There was a tendency for the basic amino-acids (lysine, histidine, and arginine) and the aromatic amino-acids (tyrosine and phenylalanine) to be less affected than most others, but glycine, which is neither basic nor aromatic was affected even more than they. One is reminded of Wool's plaintive comment in another context about insulin's selective actions⁹: "There is nothing . . . that allows systematic sense to be made of the findings". It is interesting, however, that a fair correlation was present between the relative susceptibility of each amino-acid to insulin's action on cultured foetal heart tissue and the degree to which insulin alters the release of each amino-acid from the forearm of postabsorptive man *in vivo*⁹.

A net improvement in cardiac protein and amino-acid balance could be mediated by a change in any or all of three metabolic

Fig. 2 Amino-acid release from 19–20 day foetal mouse hearts maintained in organ culture for three days. The mean ± 1 s.e.m. are shown for each of 16 amino-acids. Hearts from matched litter mates were cultured in Earle's salt solution with or without 50 $\mu\text{g}/\text{ml}$. of insulin. Atmosphere = 95% $\text{O}_2 + 5\%$ CO_2 ; temperature = 37.5° C. Black columns, insulin absent; stippled columns, insulin present.



processes which may be sensitive to insulin: membrane transport of amino-acid, protein synthesis, and proteolysis^{8,10,11}. From the present data one cannot differentiate which of these factors were important in these experiments. Changes in membrane transport and cellular uptake apparently cannot account for the entire action since all amino-acids are affected, even those that are known not to have their uptakes altered by insulin⁸. Nevertheless, alterations in cellular uptake may play at least a partial role for some amino-acids, even in experiments using amino-acid-free media, since re-uptake of the released compounds probably continues to some degree. In addition, it seems likely that the hormone's ability to stimulate protein synthesis from intracellular amino-acids would be of importance^{8,10}. Finally, the possible role of insulin in reducing proteolysis¹¹, either by inhibiting the release of lysosomal enzymes or by some other mechanism, deserves careful attention.

Whatever the mechanisms involved, it is clear that insulin has the ability to reduce the long-term net loss of proteins and amino-acids from foetal mouse hearts *in vitro*. At the same time, it prolongs their duration of function³ just as it has been supposed to preserve the function of isolated hearts in other systems, including beating human hearts being preserved for future transplantation¹². It is suggested that these actions of the hormone may be related and that improved cardiac survival and function *in vitro* may be due in part to inhibition by insulin of the net breakdown of essential proteins.

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- ¹ Wildenthal, K., *J. Appl. Physiol.*, **30**, 153 (1971).
- ² Fell, H. B., Dingle, J. T., Coombs, R. R. A., and Lachmann, P. J., in *Differentiation and Immunology* (edit. by Warren, K. B.), 49 (Academic Press, London and New York, 1968).
- ³ Wildenthal, K., *J. Molec. Cell. Cardiol.*, **1**, 101 (1970).
- ⁴ Hughes, D. M., and Longmore, D. B., *Nature*, **235**, 334 (1972).
- ⁵ Wildenthal, K., *J. Molec. Cell. Cardiol.*, **2**, 67 (1971).
- ⁶ Lowry, O. H., Rosebrough, N. J., Farr, A. L., and Randall, R. J., *J. Biol. Chem.*, **193**, 265 (1951).
- ⁷ Morgan, J. F., Morton, H. J., and Parker, R. C., *Proc. Soc. Exper. Biol. Med.*, **73**, 1 (1950).
- ⁸ Wool, I. G., *Federation Proc.*, **24**, 1060 (1965).
- ⁹ Pozefsky, T., Felig, P., Tobin, J. D., Soeldner, J. S., and Cahill, jun., G. F., *J. Clin. Invest.*, **48**, 2273 (1969).
- ¹⁰ Snipes, C. A., *Quart. Rev. Biol.*, **43**, 127 (1968).
- ¹¹ Morimore, G. E., and Mondon, C. E., *J. Biol. Chem.*, **245**, 2375 (1970).
- ¹² Sordahl, L. A., Liddicoat, J. E., Diethrich, E. B., Silver, B., DeBakey, M. E., and Schwartz, A., *J. Molec. Cell. Cardiol.*, **1**, 379 (1970).

Evidence for a Sex-linked Difference in Aspirin Metabolism

ASPIRIN is the most widely consumed drug on Earth. Although adverse reactions to its use are relatively rare, they are nevertheless clinically common because of the universal use of this "everyman's medicine". These complications may present as hypersensitivity reactions such as asthma and rhinorrhoea, but most often they take the form of gastric erosions and/or ulcerations with mucosal bleeding. The relative rarity of gastric complications of aspirin ingestion suggests that they occur only in individuals who, for one reason or another, are at greater risk or in circumstances, such as the prior abuse of alcohol, which favour their development. Several studies conducted in Australia provide an important clue to the identification of a population at risk from ingestion of aspirin. In 1963 Billington^{1,2} reported that the incidence of chronic gastric ulcer in women began to increase after 1943 in New South Wales, something which had not occurred in Australian men. Billington theorized that the factor responsible for this change in the epidemiology of peptic ulcer disease in that part of the world was extraneous and probably behavioural. Then, Chapman and Duggan reported a significant association between gastric ulceration in young women of New South Wales and the regular use of compounds containing aspirin^{3,4}. They found no such association with gastric ulceration in males or with duodenal ulceration in either sex. Other Australian authors have confirmed the existence of an association between chronic usage of aspirin and gastric ulceration^{5,6}. These well controlled clinical studies suggest that women who consume ASA regularly are at a greater risk of developing gastric complications than are men.

The basis of this report is an attempt to explain this phenomenon by investigating an important aspect of the metabolism of aspirin; its rapid *in vivo* hydrolysis to salicylic acid and acetic acid. The degradation of aspirin in the body which depends on an enzyme system(s) (aspirin-esterase) present in plasma, the liver and the kidney, has been appreciated for some time⁷ but has been investigated only superficially. In particular, extensive sampling of aspirin-esterase in normal and abnormal human populations remains to be done. The *in vivo* hydrolysis of aspirin relates to the problem at hand because gastric mucosal injury by aspirin (given orally or parenterally) results from the intact aspirin molecule and not from its chief metabolite, salicylic acid⁸. Also, the tendency of aspirin to increase the bleeding time (an action which can be expected to compound the effects of aspirin on the gastric epithelium) by interfering with platelet aggregation, is due to the intact molecule of aspirin and not to salicylic acid^{9,10}. Parenthetically, it has long been suspected that the analgesic action of aspirin—a less quantifiable aspect of its pharmacodynamic spectrum—is also an effect of the unhydrolysed acetylesther¹¹. In the light of this information we have approached the problem of the apparent greater susceptibility of women to aspirin by comparing the rates at which sera from normal men and women degrade the drug.

The assay of aspirin-esterase in serum consists in the esti-

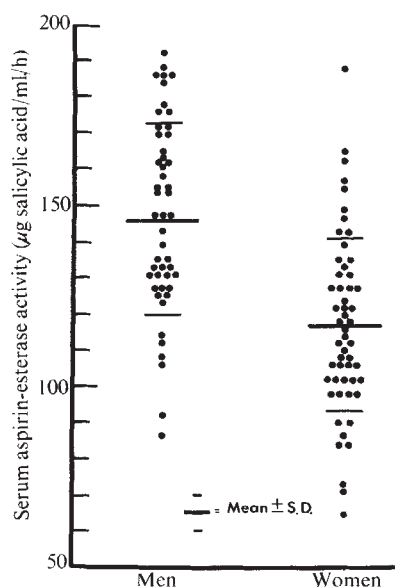


Fig. 1 Aspirin-esterase activity (μg of salicylic acid released/ml. of serum/60 min) levels in the sera of 104 normal men (50) and women (54). The means of the two groups were significantly different ($P < 0.001$).

mation of the quantity of salicylic acid released from the substrate, aspirin, in standard conditions of pH and temperature. Serum (0.5 ml.) is incubated with a 15 mM solution (0.4 ml.) of aspirin and 0.06 M Tris-HCl buffer, pH 7.0 (2.1 ml.) in a shaking water bath (25°C) for 60 min. The released salicylic acid is estimated by an adaptation of the method of Brodie¹². Appropriate blanks without aspirin or serum are included with each incubation. Enzyme activity is expressed as μg of salicylic acid/ml. of serum/60 min. In routine conditions the coefficient of variation of the assay method was 0.92%. The intra-individual coefficient of variation (mean coefficient of variation of two assays at an average interval of 6 months in fourteen subjects) was 4.9%.

Our study was conducted with 104 Caucasian subjects, fifty male (average age, 30) and fifty-four female (average age, 27). Regular users of aspirin were excluded from the study. The data are summarized in Fig. 1, which shows that levels of aspirin-esterase in serum vary considerably from one individual to another, something which had already been noted¹¹. When values from men and women were separated, we found that the average values (146.8 and 117.4 respectively) are significantly different ($P < 0.001$).

It has been estimated that the aspirin-esterase activity in the human blood volume accounts for about 20% of total hydrolysis of a dose of aspirin with the remainder taking place in the liver¹³. It seems reasonable to assume that individuals with very low serum levels of aspirin-esterase might degrade aspirin more slowly and thus be more susceptible to the pharmacological effects of the intact acetylesther. This would be comparable with the well known susceptibility of subjects with low serum levels of pseudocholinesterase (a similar but probably not identical enzyme) to the use of succinylcholine during surgical operations. These data could explain why women seem more prone to develop at least one of the adverse reactions to the use of aspirin. It could be argued that the lower serum aspirin-esterase in young women, rather than being sex-linked, is related to some extraneous factor (such as a greater consumption of aspirin for dysmenorrhoea). However, we did exclude from our studies subjects whose use of aspirin was a regular habit. Moreover, we have found that aspirin-esterase activity in liver homogenates is much lower in female than in male rats, which suggests that this activity in blood and tissues is indeed sex-linked.

Because it is likely that the analgesic and anti-inflammatory

effects of aspirin are properties of the intact molecule of aspirin rather than of its chief metabolite, salicylic acid¹¹, it may be worthwhile to establish therapeutic doses of aspirin on the basis of a given patient's ability to metabolize it rather than using arbitrary standards.

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- ¹ Billington, B. P., *Austral. Ann. Med.*, **12**, 153 (1963).
- ² Billington, B. P., *Gut*, **6**, 121 (1965).
- ³ Chapman, B. L., and Duggan, J. M., *Gut*, **10**, 443 (1969).
- ⁴ Duggan, J. M., and Chapman, B. L., *Med. J. Austral.*, **7**, 797 (1970).
- ⁵ Douglas, R. A., and Johnston, E. D., *Med. J. Austral.*, **2**, 893 (1961).
- ⁶ Gilles, M. A., and Skyring, A., *Med. J. Austral.*, **2**, 280 (1969).
- ⁷ Vandelli, L., and Scaltriti, F., *Boll. Soc. Ital. Biol. Sper.*, **21**, 77 (1943).
- ⁸ Brodie, D. A., and Hooke, K. F., *Diges. Dis.*, **16**, 985 (1971).
- ⁹ Quick, A. J., *Amer. J. Med. Sci.*, **252**, 265 (1966).
- ¹⁰ O'Brien, J. R., *Lancet*, **i**, 779 (1968).
- ¹¹ Morgan, A. M., and Truitt, E. B., *J. Pharm. Sci.*, **54**, 1640 (1965).
- ¹² Brodie, B. B., Udenfried, S., and Coburn, A. F., *J. Pharmacol. Exp. Therap.*, **80**, 114 (1944).
- ¹³ Rowland, M., and Riegelman, S., *J. Pharm. Sci.*, **57**, 1313 (1968).

Transformation of Mouse Cells infected with AKR Leukaemia Virus induced by Smog Extracts

A NUMBER of *in vitro* assay systems¹⁻⁴, useful for chemical carcinogenesis studies, exploit the observation that preinfection of cells with "nontransforming" RNA tumour viruses lead not only to accelerated transformation but also to transformation not inducible by the carcinogens alone⁵.

We have reported that mouse cells chronically infected with AKR leukaemia virus were readily transformed by the chemical carcinogens 3-methylcholanthrene (3MC)⁶, 7,12-dimethylbenz(a)anthracene (DMBA)⁶ and benzo(a)pyrene (BP)⁶, whereas cells treated with virus or chemical alone were not transformed. Subsequently we compared the transforming activity of BP *in vitro* on three cell lines, rat and mouse cells infected with C-type RNA viruses and uninfected hamster cells, and found that the mouse cells preinfected with a C-type RNA virus provided the most rapid and sensitive assay system for measuring carcinogenic potential⁷.

Transformation of rat and hamster cells by crude extracts of city smog was recently reported by Freeman *et al.*⁸; uninfected rat embryo cultures were not transformed, but cultures chronically infected with Rauscher leukaemia virus were transformed. Hamster embryo cultures infected with hamster leukaemia virus were sensitive to the transforming effects of smog; although uninfected hamster cultures were also transformed, ten-fold higher doses of the smog extract were required. We describe here transforming activity in the AKR leukaemia virus infected mouse cell system by three city smog extracts, including the same extract tested previously by Freeman *et al.*⁸ We also report production of sarcomas in newborn mice by most of the transformed cell lines derived from the transformed cultures.

AKR leukaemia virus was obtained from Dr J. W. Hartley, National Institute of Allergy and Infectious Diseases, as

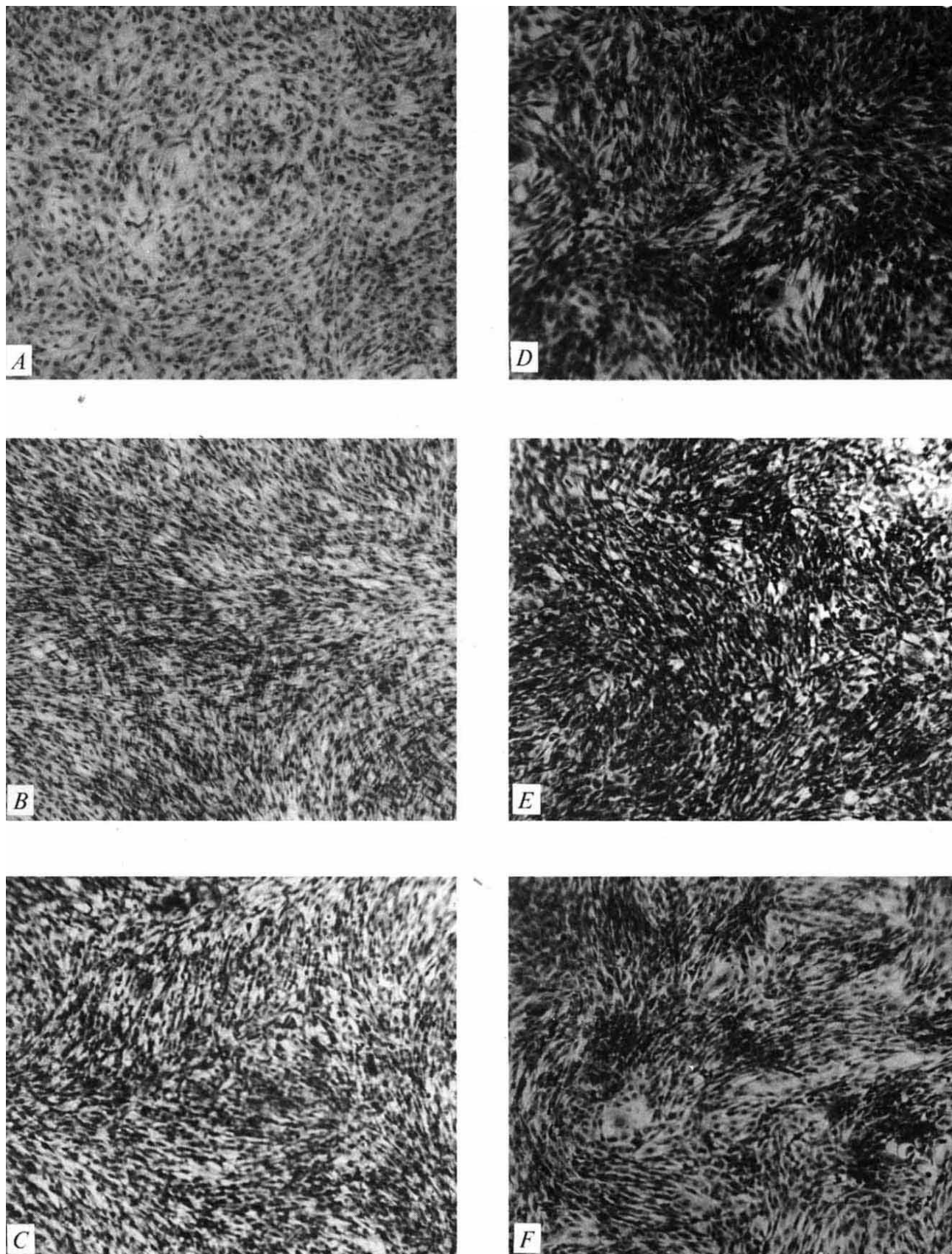


Fig. 1 AKR leukaemia virus infected NIH mouse embryo (AKR-NIH-ME) cells. The cultures treated for 7 days with extracts of city smog or carcinogenic chemicals, followed by four subcultures (42 days) in nutrient medium. Giemsa stain ($\times 36$). *A*, Cells, no treatment (0.01% acetone); *B*, cells treated with BP ($1 \mu\text{g}/\text{ml.}^{-1}$); *C*, cells treated with DMBA ($0.01 \mu\text{g ml.}^{-1}$); *D*, cells treated with smog A ($10^{-2} \mu\text{g unit mol.}^{-1}$); *E*, cells treated with smog B ($10^{-3} \mu\text{g unit ml.}^{-1}$); *F*, cells treated with smog C ($10^{-2} \mu\text{g unit ml.}^{-1}$). Note the morphological changes in AKR-NIH-ME cells treated with chemical carcinogens and smog extracts; criss-crossing, spindle-shaped cells with nuclear and cytoplasmic overlapping (*B-F*).

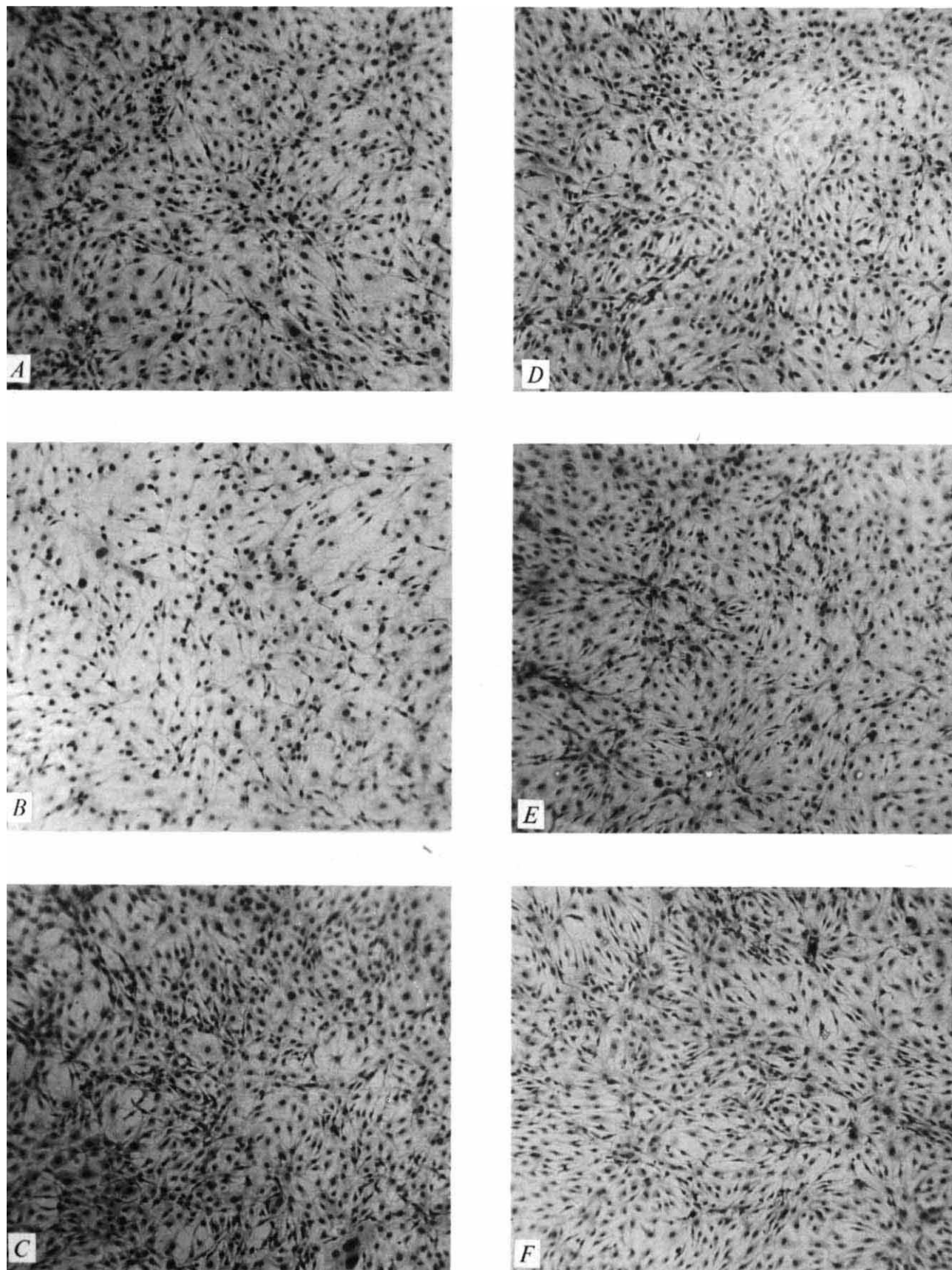


Fig. 2 Swiss NIH mouse embryo (virus-free) cells. The cultures treated for 7 days with extracts of city smog or carcinogenic chemicals followed by four subcultures (42 days) in nutrient medium. Giemsa stain ($\times 36$). *A*, Cells, no treatment (0.01% acetone); *B*, cells treated with BP ($1 \mu\text{g ml}^{-1}$); *C*, cells treated with DMBA ($0.01 \mu\text{g ml}^{-1}$); *D*, cells treated with smog A ($10^{-2} \mu\text{g unit ml}^{-1}$); *E*, cells treated with smog B ($10^{-3} \text{ unit ml}^{-1}$); *F*, cells treated with smog C ($10^{-2} \mu\text{g unit ml}^{-1}$).

Table 1 Organic Materials extracted from Particulate Matter filtered from the Air in Los Angeles

Sample	A	B	C
Dates collected	6/1/70 to 6/2/70	3/8/70 to 27/8/70	8/8/69 to 27/8/70
Average concentration benzene-solubles in air, $\mu\text{g m}^{-3}$	21	21	21
Benzo(a)pyrene, $\mu\text{g g}^{-1}$ extract	77	23	42
Benz(a)anthracene, $\mu\text{g g}^{-1}$ extract	72	12	24
Benzo(e)pyrene, $\mu\text{g g}^{-1}$ extract	177	71	103
Chrysene, $\mu\text{g g}^{-1}$ extract	150	53	114

fourteenth passage tissue culture fluid pool (No. 1617) and was passed twice in NIH Swiss mouse embryo (NIH-ME) cells before being used in this experiment.

Primary cultures of NIH-ME cells were obtained from Microbiological Associates, Inc., Bethesda, Maryland. Growth and maintenance medium consisted of Eagle's minimal essential medium with 10% foetal bovine serum, 2 mM glutamine, 100 U/ml. penicillin and 100 $\mu\text{g/ml}$. streptomycin (EMEM + 10% FBS).

AKR leukaemia virus infected and uninfected NIH-ME lines used in this study have been described in detail^{6,7}. Secondary cultures of NIH-ME cells after inoculation with AKR leukaemia virus became continuously infected carrier cultures which regularly produced complement-fixing (CF) antigens characteristic of the murine leukaemia-sarcoma virus complex, and yielded infectious virus (3.0-4.0 logs of virus/ml.) when tested in the *in vitro* COMUL test⁸. Cell pack preparations from infected and uninfected NIH-ME cells were made and tested for gs antigen as previously described⁹. Complement fixation tests were carried out by the microtitre technique described for tumour and viral antigen studies¹⁰. Titres were recorded as reciprocals of the highest dilution giving 3+ to 4+ fixation of 1.8 units of complement.

The three samples of extracts of airborne particulate matter tested were collected at different times in the same year on large pleated glass fibre filters at a central location in Los Angeles

(Table 1). Samples A and B were collected continuously throughout the periods indicated, whereas sample C was a composite of samples from eight monthly collection periods throughout the annual interval shown, and this extract has been studied by Freeman *et al.*⁸ for its transforming ability in rat and hamster cells. The glass fibre filters were individually extracted with benzene in a large 'Soxhlet' extractor, about 90% of benzene removed by distillation and the remainder by evaporation at low temperature and pressure in a rotary evaporator. The samples were analysed for selected polynuclear aromatic hydrocarbons by chromatography and ultraviolet spectrometry (unpublished work). The results for four components are shown in Table 1. All four components are known or suspected carcinogens; benzo(a)pyrene has strong activity, the others are weak or not well established as active. There may well be other carcinogens not yet identified also present.

The residues were dissolved in acetone to yield a stock solution of 10 μg units ml^{-1} . The equivalent concentration of BP in smog residue will be referred to as μg units: (1) Sample A: 1 μg unit of smog contained approximately 13,000 μg of residue of which 1 μg was BP. (2) Sample B: 1 μg unit of smog contained approximately 43,000 μg of residue of which 1 μg was BP. (3) Sample C: 1 μg unit of smog contained approximately 23,000 μg of residue of which 1 μg was BP.

Benzo(a)pyrene (BP) and DMBA were obtained from Eastman Organic Chemicals and were dissolved in 1 ml. of acetone to yield a stock solution of 100 $\mu\text{g ml}^{-1}$, which was stored in the dark at 4° C.

One day after both AKR leukaemia virus infected and uninfected mouse cells at the sixteenth subculture were plated at a density of 2×10^5 cells in Falcon plastic Petri dishes, the media were removed and replaced with media containing various concentrations of smog extracts, DMBA (0.01 $\mu\text{g ml}^{-1}$) or BP (1 $\mu\text{g ml}^{-1}$). The media for the control cells contained 0.01% acetone. After 7 days of treatment with experimental media, the cultures were washed and fed again with smog-free or carcinogen-free growth medium and subdivided by trypsin treatment. Additional subcultures were prepared every 7-10 days thereafter. When changes in mor-

Table 2 Transformation in AKR Leukaemia Virus Infected NIH Mouse Embryo (AKR-NIH-ME) Cells* treated with Extracts of City Smog or Chemicals†

Passage	Cumulative No. of days after smog or chemical treatment	Morphological Changes in AKR-NIH-ME cells									
		Smog A ($\mu\text{g unit}^\ddagger \text{ ml}^{-1}$)			Smog B ($\mu\text{g unit}^\ddagger \text{ ml}^{-1}$)			Smog C ($\mu\text{g unit}^\ddagger \text{ ml}^{-1}$)			
		10^{-2}	10^{-3}	10^{-4}	10^{-3}	10^{-4}	10^{-2}	10^{-3}	10^{-4}	DMBA 0.01 $\mu\text{g ml}^{-1}$	BP 1 $\mu\text{g ml}^{-1}$
Primary	14	+	—	—	—	—	+	—	—	+	—
2	21	+	±	—	+	—	+	—	—	+	—
3	28	+	+	—	+	—	+	—	—	+	—
7	68	+	+	—	+	—	+	—	—	+	—

* AKR-infected NIH-ME cells (R-616X, passage 16).

† Cells were treated with extracts of smog or chemicals for 7 days.

‡ The equivalent concentration of BP in smog residue is referred to as μg unit.

Table 3 Transformation in AKR Leukaemia Virus Infected NIH Mouse Embryo (AKR-NIH-ME) Cells* treated with Extracts of City Smog or Chemicals†

Passage	Cumulative No. of days after smog or chemicals removed	Morphological alterations in NIH-ME cells									
		Smog ($10^{-2} \mu\text{g unit}^\ddagger \text{ ml}^{-1}$)			AKR infected BP 1 $\mu\text{g ml}^{-1}$			Uninfected BP 1 $\mu\text{g ml}^{-1}$			
		A	B	C	DMBA 0.01 $\mu\text{g ml}^{-1}$	Acetone 0.01 %	Smog A ($10^{-2} \mu\text{g unit}^\ddagger \text{ ml}^{-1}$)	B	C	DMBA 0.01 $\mu\text{g ml}^{-1}$	Acetone 0.01 %
4	32	+	+	+	+	—	—	—	—	—	—
7	73	+	+	+	+	—	—	—	—	—	—

* AKR infected NIH-ME cells (R-616U, passage 21) and uninfected NIH-ME cells (R-616UTC, passage 21).

† Cells were treated with extracts of smog or chemicals for 4 days.

‡ The equivalent concentration of BP in smog residue is referred to as μg unit.

phology and growth patterns appeared, some cultures were fixed in alcohol and stained with Giemsa for further microscopy. Both transformed and untransformed cultures were established as continuous cell lines.

The AKR leukaemia virus-infected mouse cells were transformed by doses of smog up to 10^{-2} μg unit ml^{-1} or by chemicals—BP (1.0 μg ml^{-1}) or DMBA (0.01 μg ml^{-1}) (Table 2). Higher doses of smogs or chemicals were lethal. By contrast, the uninfected mouse cultures were not transformed by either smog extracts or chemicals. Altered cell foci were found in the virus infected cultures, approximately 14 to 21 days after removal of the medium containing smog extracts or chemicals. As in previous studies⁵⁻⁷, the infected cells that were not treated with smog extracts or chemicals remained normal in appearance. The transformed foci consisted of randomly oriented, spindle-shaped cells showing a loss of contact inhibition and were similar to those observed in a previous study of 3MC and BP transformed AKR-infected NIH-ME cells⁵⁻⁷. When smog or chemical treated, virus-infected cultures were observed for an additional week, the piled-up colonies present in all plates increased in size. When stained with Giemsa, the transformed foci were darkly stained against a lighter background of untransformed cells that remained as a monolayer. After four additional subcultures, the transformed cells completely replaced the original fibroblastic-like monolayers (Fig. 1B-F). By contrast, the cellular morphology remained unchanged in untreated AKR-infected and uninfected NIH-ME lines treated with smog or chemical alone, continuing to grow in monolayers of normal appearing fibroblast-like cells (Figs. 1A and 2) although they were subcultured seven times during the ensuing 68 days after the smog or chemical treatment (Table 2). Increased growth rates were observed in the smog and chemically transformed cultures, since they had to be subcultured more frequently than the untreated untransformed cultures.

The transformed cell lines were tested also for their ability to transplant and produce tumours in newborn NIH Swiss mice. Two smog transformed cell lines (smog A, 10^{-3} μg unit ml^{-1} , and smog C, 10^{-2} μg unit ml^{-1}) were tumorigenic; however, one smog transformed cell line (smog B, 10^{-3} μg unit ml^{-1}) and the untransformed cells were not successfully transplanted. The tumours developed very quickly at the site of inoculation (an average latent period of 5 days); as observed previously⁵, however, the tumours regressed 7–10 days later. Several of the tumours described as sarcomas were removed and trypsinized before regression and cells re-established in culture. Both the cells and the mouse tumours contained virus specific murine leukaemia virus CF antigens and electron microscopy performed by Dr M. L. Vernon of Microbiological Associates revealed large numbers of C-type virus particles.

An additional experiment to test reproducibility of transforming effects of smog extracts was carried out using another AKR leukaemia virus infected NIH-ME cell (R-616U) and a sister, uninfected NIH-ME cell line. The method of treatment was the same as already described except that the period of treatment with smog extracts was 4 days instead of 7 days. The results were similar to those of the first experiment, only the infected cells were transformed, whereas treated but uninfected cells remained normal in appearance for 73 days after the treatment period (Table 3). The transformed cells from all three smog extracts produced tumours when transplanted into newborn NIH Swiss mice. The tumours containing gs antigen grew progressively, some reaching 5 cm in diameter within 12 weeks after inoculation. The tumours were sarcomas and composed mainly of large spindle-shaped cells with ovoid nuclei, many with prominent nucleoli.

The concentration of smog containing 0.01 – 0.001 μg units ml^{-1} of BP transformed infected ME cells as efficiently as 1 μg ml^{-1} of pure BP. However, there was only one part of BP for each 13,000 to 43,000 parts of total smog residue, indicating that the smog residue contained transformation-promoting agents other than BP. Similar findings were reported in the previous studies with smog extracts tested *in vitro*⁸ and *in vivo*

system¹¹⁻¹⁶. Freeman *et al.*⁸ found that the smog extracts were 600 times more active than pure BP, in terms of BP units, as transforming agents. We found them 100 times to 1,000 times as active. Kotin *et al.*¹⁶ reported that substances other than BP were involved in causing or promoting the tumours since the concentration of BP in their atmospheric preparation could not account for the number of skin tumours observed. Further studies will be needed to identify the components of smog which are the most active as transforming agents.

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Received March 20; revised May 16, 1972.

- ¹ Freeman, A. E., Price, P. J., Igel, H. J., Young, J. C., Maryak, J. M., and Huebner, R. J., *J. Nat. Cancer Inst.*, **44**, 65 (1970).
- ² Price, P. J., Freeman, A. E., Lane, W. T., and Huebner, R. J., *Nature New Biology*, **230**, 144 (1970).
- ³ Rhim, J. S., Vass, W., Cho, H. Y., and Huebner, R. J., *Intern. J. Cancer*, **7**, 65 (1971).
- ⁴ Rhim, J. S., Vass, W., Cho, H. Y., and Huebner, R. J., *Proc. Amer. Assoc. Cancer Res.*, **12**, 23 (1971).
- ⁵ Rhim, J. S., Creasy, B., and Huebner, R. J., *Proc. US Nat. Acad. Sci.*, **68**, 2212 (1971).
- ⁶ Rhim, J. S., Creasy, B., Joglekar, M. H., Vass, W., and Huebner, R. J., *Bact. Proc.*, 217 (1971).
- ⁷ Rhim, J. S., Cho, H. Y., Joglekar, M. H., and Huebner, R. J., *J. Nat. Cancer Inst.* (in the press).
- ⁸ Freeman, A. E., Price, P. J., Bryan, R. J., Gordon, R. J., Gilden, R. V., Kelloff, G. J., and Huebner, R. J., *Proc. US Nat. Acad. Sci.*, **68**, 445 (1971).
- ⁹ Hartley, J. W., Rowe, W. P., Capps, W. I., and Huebner, R. J., *Proc. US Nat. Acad. Sci.*, **53**, 931 (1965).
- ¹⁰ Huebner, R. J., Rowe, W. P., Turner, H. C., and Lane, W. T., *Proc. US Nat. Acad. Sci.*, **50**, 379 (1963).
- ¹¹ Passey, R. D., *Brit. Med. J.*, **2**, 1112 (1922).
- ¹² Kennaway, E. L., *J. Path. Bact.*, **27**, 233 (1924).
- ¹³ Leiter, J., Shimkin, M. B., and Shear, M. J., *J. Nat. Cancer Inst.*, **3**, 155 (1942).
- ¹⁴ Campbell, J. A., *Brit. J. Exp. Path.*, **15**, 287 (1934).
- ¹⁵ McDonald, S., Jr., and Woodhouse, D. L., *J. Path. Bact.*, **54**, 1 (1942).
- ¹⁶ Kotin, P., Falk, H. L., Mader, P., and Thomas, M., *AMA Arch. Ind. Health*, **9**, 153 (1954).

Teratogenicity of Hycanthone in Mice

HYCANTHONE methanesulphonate, a drug believed to be effective in the treatment of schistosomiasis, is being administered to many individuals in Africa and Brazil during extensive field studies (therapeutic doses are 3–4 mg/kg). Studies have shown that hycanthone is mutagenic in bacterial¹ and mammalian cell² systems. This demonstrated mutagenic activity, plus the daily administration of the drug to large numbers of people, suggested that hycanthone methanesulphonate be evaluated for teratogenic capabilities.

Pregnant, primiparous, random bred mice of the CD-1 stock were procured (Charles River) with known breeding dates. The date a cervical plug was observed denoted day zero of pregnancy. All animals had continual access to food and water.

To simulate the therapeutic regimen used in the treatment of schistosomiasis, a single, intramuscular dose of hycanthone

Table 1 Effects of Hycanthone on Pregnant Mice

Dose (mg/kg)	Gestation day administered	Litters (No.)	Live foetuses per litter (av. No.)	Foetal mortality per litter (%)	Foetal body wt. (g)	Abnormal litters (No.)	Abnormal foetuses per litter (%)
0*	7	27	11.7	7.9	1.13†	2	<1
10	7	17	12.2	3.9	1.12	1	<1
35	7	18	11.2	15.1	0.97‡	14	30.7
50	7	19	7.3	44.6	0.92	15	49.2
50	7, 8, 9	10	1.4	91.0	1.14	—	—

* Received either HBSS or sterile water for injection; ten animals received injections on days 7, 8, 9.

† Based on data obtained from twenty litters.

‡ Based on data obtained from eleven litters.

Table 2 Incidence of Specific Congenital Malformations in Litter from Hycanthone-treated Mice *

Dose (mg/kg)	Litters examined (No.)	Exencephaly		No. of litters and % of foetuses per litter examined with Hydrocephaly		% of foetuses per litter examined with Microphthalmia		Skeletal		Other	
		Litters	%	Litters	%	Litters	%	Litters	%	Litters	%
0	27	1	0.3	0	0	0	0	0	0	1	0.2
10	17	0	0	0	0	0	0	0	0	1	0.4
35	18	4	2.5	9	23.3	8	11.4	4	16.7	6	4.4
50	19	8	17.3†	9	23.3	9	14.8	10	46.9‡	7	8.9

* $P < 0.05$ for each malformation incidence at the 35 and 50 mg/kg dose.

† $P < 0.05$ when compared with 35 mg/kg dose.

methanesulphonate was administered on day 7, except for one group which received additional injections on days 8 and 9, and appropriate control groups. The stage of gestation selected for drug administration coincides with the period of extensive organogenesis in the mouse. Hycanthone methanesulphonate was solubilized in either Hanks balanced salt solution or sterile water for injection within 60 min of the time it was to be used. The volume administered varied between 50 μ l. and 75 μ l. dependent on dose which was calculated from the average weight of mice on gestation day 7.

The mothers were killed on gestation day 16½ or 17 and the pups removed by Caesarean section. The third and seventh foetus in each litter was stained with alizarine red for examination of skeletal development. All other foetuses were stored in Bouin's fixative and subsequently examined for visceral defects by gross serial sectioning.

The following procedure was observed in compiling the data (Tables 1 and 2). Three experiments are combined because replicate results were similar. A foetus is listed as dead if either dead or resorbed. Only live foetuses were examined for abnormalities and a foetus is classified as abnormal if it had at least one type of anomaly. A litter is classified abnormal if it contained at least one abnormal foetus.

The variables expressed in % were derived by first obtaining the percentage for each litter and then calculating the average of these percentages. The denominator for each variable was the actual number of foetuses examined for the specific variable. Of the malformations listed, microphthalmia needs definition. No attempt was made to differentiate anophthalmia from microphthalmia; therefore, a foetus was listed as having microphthalmia if one of its eyes was reduced in size or not found.

The statistical procedures used were the nested analysis of variance for foetal weight; Fisher's exact test or standard corrected χ^2 test for the % incidence of affected litters, and the Mann Whitney U test for the % affected foetuses per litter.

No differences in the average number of live foetuses per litter or in % foetal mortality were seen in mice which received 0, 10, or 35 mg/kg hycanthone (Table 1). Significant reductions ($P < 0.01$) in foetal viability with a concomitant increase in foetal mortality occurred at the 50 mg/kg dose level administered

on day 7. The same dose level administered on days 7, 8, and 9 resulted in total foetal resorption in nine instances out of ten. Foetal body weight was lower at the 35 mg/kg ($P < 0.05$) and 50 mg/kg ($P < 0.01$) dose administered on day 7. Maternal weight gain was similar in all groups that received a single dose. The group that received 50 mg/kg on days 7, 8, and 9 had decreased weight gain suggesting that maternal toxicity may have contributed to the high foetal wastage.

At the 35 and 50 mg/kg dose, malformations occurred in more than three-quarters of the litters, with the percentage of abnormal foetuses in a litter increasing with dose. The single malformation observed at the 10 mg/kg dose (cleft palate) is not felt to be drug associated since a similar malformation occurred in the controls.

Three visceral malformations, exencephaly, hydrocephaly, and microphthalmia, were consistently seen at the 35 and 50 mg/kg dose (Table 2). The number of litters involved and the percentage of foetuses within a litter with exencephaly were greatest at the high dose.

The skeletal malformations found were fusion and branching of ribs. Cranial bone malformation accompanying exencephaly was not tabulated. Foetuses from mothers who received the high dose of hycanthone had an increased frequency of rib malformations.

The "other" anomalies tabulated in Table 2 were meningocele, cleft palate, cleft lip, gastroschisis, and diaphragmatic hernia. The frequency of occurrence was similar at the two high doses and in most instances the foetuses with these defects had multiple malformations.

Finding hycanthone methanesulphonate to be a potent teratogen in mice is to my knowledge the first indication of the drug's potential for production of congenital anomalies. A teratogenic dose response is suggested by an increase in % abnormal foetuses per litter plus increased incidence of exencephaly and rib anomalies at the high dose. Its teratogenic potential in other mammalian species should be investigated so that consideration may be given towards the desirability of the drug's administration to pregnant women. It also seems appropriate to determine the role that hycanthone *per se*, or the methanesulphonate salt, has in the production of these malfunctions.

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¹ Hartman, P. E., Levine, K., Hartman, Z., and Berger, H., *Science*, **172**, 1058 (1971).

² Clive, D., Flamm, W. G., and Machesko, M. R., *Mutation Res.*, **14**, 262 (1972).

Multiple Sex Pheromones of the Codling Moth, *Laspeyresia pomonella* (L.)

NUMEROUS sex pheromones of Lepidoptera have now been identified and synthesized. In general, one or two sex pheromones per species have been reported except that three were found in the silkworm moth, *Bombyx mori* (L.)¹. If an insect contains more than one sex pheromone, it is important that they all be detected before undertaking structure determination and synthesis, since a single sex pheromone may be unattractive by itself^{2,3}. Also, even if it were attractive, the presence of undetected sex pheromones would make it possible for the insect to develop resistance to being controlled by trapping.

Our experience indicates that the standard procedures used for isolation of sex pheromones from extracts of abdominal tips or of whole insects, will not reveal the presence of all sex pheromones. Previously, in two separate studies only one sex pheromone of the codling moth, *Laspeyresia pomonella* (L.), was found in extracts of whole females⁴ or abdominal tips of females⁵. Nevertheless, we now report that female codling moths emit several sex pheromones.

In a study to determine the attractiveness of a sex pheromone isolated from female codling moths, tests in an apple orchard showed that partially purified pheromone attracted more, while pure pheromone attracted fewer, males than females⁶. The tests with the purified pheromone, however, were too limited to be free of the possibility of statistical error. Accordingly, more extensive tests were then conducted in a field cage (7.9 m wide by 3.6 m high by 22 m long) maintained by heaters at 24° C. Here traps baited with ten live, virgin females caught 500 males while an equal number of traps baited with an optimum amount (50 µg) of purified natural sex pheromone caught ninety-two. Thus, another chemical, important for attractancy in the field, had been removed during purification: either a synergist or another attractant.

An attempt to find evidence of another sex pheromone in extracts of whole female bodies by gas chromatography was unsuccessful. Because masking⁷ might have been a factor, and it is unlikely that unmated females would release a masking agent to their own pheromones, condensed vapours from virgin females were studied. Air was passed over 500 females 2-4 days old in a 15-l. jar at the rate of 20 ml/min into 150 ml. of dichloromethane at 24° C. The air leaving the jar was filtered with a plug of glass wool to remove scales. Any evaporated dichloromethane was replenished each day and 200 ml. of 8% sucrose solution was provided for food. After 4 days, the dichloromethane solution was concentrated to 1 ml. Portions of this solution were then injected into a gas chromatograph equipped with an 'Apiezon-L' column. The gas chromatograph was operated at several temperatures in order to cover a volatility range represented by that from hexanol to octadecanol. Eluted samples were collected each minute and in

Table 1 Retention Indexes of Sex Pheromones of Codling Moth at the Indicated Temperatures on an 'Apiezon-L' Column and Minimum Concentration (Female Equivalents/ml.) of each Pheromone required to elicit Positive Bioassay

No.	Retention index	Temp. (°C)	Minimum concentration
1	1069	90	10 ⁻⁵
2	1141	90	10 ⁻⁵
3	1262	130	10 ⁻⁵
4	1342	130	10 ⁻⁹
5	1510	160	10 ⁻⁵
6	1633	180	10 ⁻⁵
7	1795	180	10 ⁻⁷

repeat runs each 0.5 minute in the region of interest and quantitatively bioassayed⁴. The bioassay is based on mating stimulation and consists of increased movement, spinning, and attempted mating. Quantitation is achieved by determining the lowest concentration which will elicit response.

Seven sex pheromones were detected in the collected fractions. Fractions collected between those containing the pheromones elicited no response in the bioassay. Table 1 gives the minimum concentration at which each sex pheromone elicits a response and the retention times expressed as retention indexes⁸ at the given temperatures. During the bioassay, we observed no difference in the response of males to any of the seven pheromones. Pheromone No. 5 is the one isolated previously⁴. Subsequently, each of the pheromones has been isolated in µg quantities from extracts of whole female bodies by procedures to be described elsewhere. At present the role of all these sex pheromones is unknown. They may not all be required for attractancy.

Other work at this laboratory with this technique has revealed a similar number of sex pheromones in the zebra caterpillar moth, *Ceramica picta* (Harris). Thus, this large number of sex pheromones could be common for Lepidoptera. Multiple sex pheromones may explain the weak attractancy of some of the synthesized sex pheromones and the ability of two Lepidoptera species having one or more sex pheromones in common to maintain isolation of species, as suggested by Ganyard and Brady⁹.

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¹ Bayer, E., *J. Gas Chromatog.*, **4**, 67 (1966).

² Jacobson, M., Redfern, R. E., Jones, W. A., and Aldridge, M. H., *Science*, **170**, 542 (1970).

³ Meijer, G. M., Ritter, F. J., Persoons, C. J., Minks, A. K., and Voerman, S., *Science*, **175**, 1469 (1972).

⁴ McDonough, L. M., George, D. A., Butt, B. A., Jacobson, M., and Johnson, G. R., *J. Econ. Entomol.*, **62**, 62 (1969).

⁵ Roelofs, W., Comeau, A., Hill, A., and Milicevic, G., *Science*, **174**, 297 (1971).

⁶ McDonough, L. M., George, D. A., Butt, B. A., Gamey, L. N., and Stegmeier, M. C., *J. Econ. Entomol.*, **65**, 108 (1972).

⁷ Jacobson, M., *Science*, **163**, 190 (1969).

⁸ Wehrli, A., and Kovats, E., *Helv. Chim. Acta*, **42**, 2709 (1959).

⁹ Ganyard, M. C., and Brady, U. E., *Nature*, **234**, 415 (1971).

Transferable Chloramphenicol Resistance in *Salmonella typhi*

WE report an outbreak of typhoid from which *Salmonella typhi* strains carrying R factors to multiple antibiotics including chloramphenicol have been isolated. Transferable drug resistance is common in *Salmonella* species which cause food poison-

ing^{1,2} but not in *S. typhi*, and no epidemic of chloramphenicol resistant typhoid fever has previously been observed³.

R factors mediating resistance to chloramphenicol, tetracycline and streptomycin are common in *Escherichia coli*, *Klebsiella* and *Proteus* strains isolated from hospital patients locally⁴ and have been transmitted *in vitro* to local isolates of *S. typhi*⁵. Chloramphenicol resistant typhoid had not hitherto been encountered in Kerala. Of 197 *S. typhi* strains isolated in Kerala during 1968–69, only five (2.5%) were found resistant to chloramphenicol⁶ at levels of 20 µg ml.⁻¹.

In May 1972, thirteen strains of *S. typhi* were isolated from blood cultures of patients, many of whom did not respond clinically to chloramphenicol treatment. In four cases the isolations were made after the patients had received chloramphenicol for 10–14 days. The sensitivity of these isolates to chloramphenicol, tetracycline, streptomycin and ampicillin was estimated by the tube dilution technique. Seven strains were found resistant to chloramphenicol, tetracycline and streptomycin with minimum inhibitory concentrations (MIC) of 500, 250 and 50 µg ml.⁻¹ respectively. The rest were inhibited by 10 µg ml.⁻¹ or less of these drugs. All strains were inhibited by 2 µg ml.⁻¹ ampicillin.

The presence of R factors in the resistant strains was tested by transfer to nalidixic-acid resistant *E. coli* K 12 F⁻ Lac⁺. Equal volumes (1 ml.) of 6 h broth cultures of *S. typhi* and *E. coli* were mixed, incubated overnight at 37° C and plated onto MacConkey's medium without bile salts, containing 20 µg ml.⁻¹ each of chloramphenicol and nalidixic acid. Resistant exconjugants were obtained in all seven cases. The parent *E. coli* had MIC of <5 µg ml.⁻¹ with chloramphenicol, tetracycline and streptomycin, and the exconjugants MIC of 500, 250 and 50 µg ml.⁻¹ respectively, as in the donor *S. typhi* strains.

Typhoid fever is endemic in Kerala and in most other parts of India and chloramphenicol has been the drug normally used in its treatment. Surveys from other parts of the world have shown that chloramphenicol resistance in *S. typhi* is infrequent^{7,8}. An unusually high incidence of chloramphenicol resistance in *S. typhi* has been reported in India⁹ and Africa¹⁰, but this was not shown to be transferable. The emergence of *S. typhi* strains carrying R factor to chloramphenicol poses a serious threat to the developing countries where the disease is endemic.

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¹ Anderson, E. S., *Ann. Rev. Microbiol.*, **22**, 131 (1968).

² Smith, H. W., *Nature*, **218**, 728 (1968).

³ Chabbert, Y. A., Baudens, J. G., and Bouanchaud, D. M., in *Bacterial Episomes and Plasmids* (edit. by Wolstenholme, G. E. W., and O'Connor, M.), 227 (Churchill, London, 1969).

⁴ Vimala, K. N., thesis, University of Calicut (1972).

⁵ Vimala, K. N., and Paniker, C. K. J., *Ind. J. Med. Res.*, **60** (in the press).

⁶ Nair, C. M. G., and Paniker, C. K. J., *Trop. Geograph. Med.*, **24** (in the press).

⁷ Agarwal, S. C., *Bull. Wld Hlth Org.*, **27**, 331 (1962).

⁸ Manton, A., Guinee, P. A. M., Kampelmacher, E. H., and Voogd, C. E., *Bull. Wld Hlth Org.*, **45**, 85 (1971).

⁹ Murti, B. R., Rajyalekshmi, M., and Bhaskaran, C. S., *J. Clin. Path.*, **15**, 544 (1962).

¹⁰ Njoku-Obi, A. N., and Njoku-Obi, J. C., *J. Bacteriol.*, **90**, 552 (1965).

Rule governing Cell Division in *Anabaena*

THE blue-green alga *Anabaena catenula* is a filamentous organism having specialized cells called heterocysts which appear at intervals along the filaments to form a spaced pattern¹. The organism grows by division of all its unspecialized vegetative

cells; heterocysts do not divide. The spacing between heterocysts is maintained by the appearance of presumptive heterocysts (proheterocysts) which develop from the vegetative cells roughly midway between previously formed heterocysts (Fig. 1). We have studied the growth of individual filaments of the organism (Cambridge Culture Collection strain 1403/1), grown on plates of a simple defined medium² consisting of mono- and di-valent cations, phosphate and trace elements, solidified with 1% agar. From sequential observations of growing filaments, we have been able to obtain complete lineage records which show the fate of every cell over several generations. The fact that it is possible to obtain such information makes the organism well suited for studies of the process of cell division and of pattern formation. In particular we have observed that cell division is asymmetrical in *A. catenula*, and that this asymmetry is governed by a simple rule.

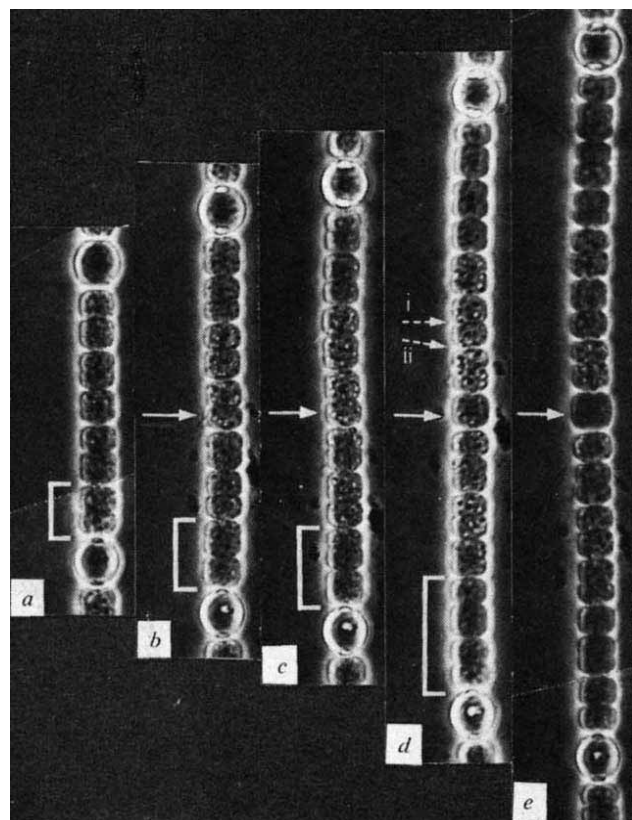


Fig. 1 Sequence of photographs of a growing *Anabaena catenula* filament, demonstrating the asymmetric division rule and the appearance of a new proheterocyst. Photographs a to e were taken at 0, 6, 10, 15 and 21 h. The division of the cell bracketed in a can be followed by referring to the bracketed cells in b, c and d. The developing stages of a proheterocyst are arrowed, from a smaller daughter cell in b to an advanced proheterocyst in e. The dotted arrows are referred to in the text. (× 800.)

We have defined a vegetative cell as the compartment bounded by two complete septa (arrow i, Fig. 1); the moment of division therefore corresponds to completion of a septum. The mean time between successive divisions of vegetative cells is 14 h. During the 4–10 h after the completion of a septum, a radially encroaching furrow separates the two adjacent vegetative cells, leaving a narrow connecting region between them (arrow ii, Fig. 1). The advantage of using the earlier stage to define an individual cell is that the completion of a septum occurs within a narrow time band, 1–2 h, so permitting precise cell counting.

Cell division is asymmetrical in the sense that one of the daughters is generally distinctly smaller than the other at the time of division, and if not, an asymmetry becomes almost

always apparent in the next round division. We can state the following rule: if a given cell has arisen as the left (right) daughter of a division, then, at its own division, its left (right) daughter will be the smaller daughter. To express this in a different way, as shown in Fig. 2, we can assign an arrow to each of the two daughters of a division, with each arrow pointing away from the newly formed septum. A cell retains this arrow until it divides. The asymmetry of a daughter cell's division is described by the direction of this arrow. We have tested this rule in more than 600 individual cell divisions and have found that it holds without exception.

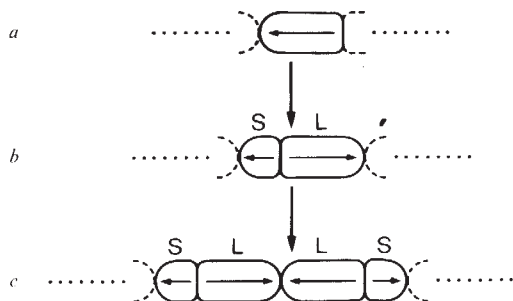


Fig. 2 The division rule. In *a* a cell of an *Anabaena* filament is represented with an arrow pointing away from the newly formed septum. The rest of the filament is indicated by dotted outlines. In *b* the two daughter cells are shown, with their relative sizes denoted by S=small, L=large. Arrows have been given to the daughters, pointing away from the new septum. In *c* the second generation is shown, using the same notation.

Both small and large daughters of a division eventually reach the same size before they divide. In general the smaller daughter of a division takes longer to reach a subsequent division than the larger (by some 20% on average) so that the cells along a filament are necessarily in different stages of the division cycle. For simplicity, this difference in division stage has been omitted from Fig. 2; generally, for a leftward-pointing arrow in the initial cell, the left-hand pair of grand-daughter cells would be smaller than the right-hand pair (for example, bracketed cells in Fig. 1).

No other case is known to the authors of asymmetrical division in a multicellular organism which is governed by a recursive rule such as we find in *A. catenula*. In bacteria which show asymmetrical placing of new septa, for example, *Bacillus cereus*, this appears not to be systematic but rather to occur at "multiple and often irregularly placed sites"³.

An analogous phenomenon does occur, however, in the stalk bacterium, *Caulobacter crescentus*⁴. In this organism, a stalked, sessile cell divides so that one half retains the stalk, while the other becomes a flagellate swarmer. The swarmer later sheds its flagellum which is replaced by a stalk. Here the states of being stalked or flagellate on division correspond to our criterion of "small" and "large" daughter cells, while the hypothetical arrow points towards the stalked or flagellated end of the bacterial cell.

It is interesting to consider what mechanism could underlie the division rule in *A. catenula*. An equivalent statement of the rule is that a new septum site always appears further from the most recently formed septum and we might conjecture that this is because the latter is surrounded by an area of disorganization or inhibition. This prompts various questions which we are currently attempting to answer. Is the asymmetrical division lost in a culture of *A. catenula* where division has slowed down and the time between formation of consecutive septa consequently increased? And is the arrow retained in isolated vegetative cells which we can remove from a filament by micromanipulation? We may also ask whether the arrow is retained by vegetative cells when they become spores, and

then expressed on germination. Although *A. catenula* does not sporulate, other species of *Anabaena*, for example, *A. cylindrica*, do form spores in dense cultures, and we have preliminary evidence that the division rule may apply to all *Anabaena* species.

Asymmetrical divisions have a connexion with heterocyst pattern formation in that heterocysts only develop from the smaller daughter of a division. Not all smaller daughter cells become heterocysts, however; this is an inhibitory zone around heterocysts⁵ within which smaller daughters do not develop. We also have evidence (which we shall shortly publish) that interactive processes prevent the development of smaller daughter cells which are too close together, although outside inhibitory zones. Thus asymmetrical division can be seen to serve as a mechanism for limiting the number of cells which are eligible to become heterocysts at any one time. In this way asymmetrical division may play an important part in many situations where specialized cells have to be singled out.

We thank Samuel Ward and Francis Crick for helpful comments on the manuscript.

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¹ Fritsch, F. E., *Proc. Linn. Soc. Lond.*, **162**, 194 (1951).

² Allen, M. B., and Arnon, D. I., *Plant Physiol.*, **30**, 366 (1955).

³ Cole, R. M., *Bact. Rev.*, **29**, 326 (1965).

⁴ Shapiro, L., Agabian-Keshishian, N., and Bendis, I., *Science*, **173**, 884 (1971).

⁵ Fogg, G. E., *Ann. Bot. NS*, **13**, 241 (1949).

GENERAL

Simultaneous Acoustic and Optical Microscopy of Biological Specimens

IN a recent article¹ we presented a brief description of an apparatus for acoustic microscopy that worked in real time and was capable of resolving detail of 25 μm using a sound wavelength of 15 μm in water, that is, at an operating frequency of 100 MHz. We report here an improved technique that allows simultaneous display of optical and acoustic images so that they may be directly compared. This combined technique should be of great value in the assessment of potential applications of acoustic microscopy.

The basic principle of the acoustic microscope has already been described in detail^{1,2}. Briefly, a sound wave is transmitted through a specimen immersed in an aqueous coupling medium. The transmitted sound, which carries the information of interest, strikes a nearby plastic mirror and generates a dynamic ripple pattern on the optically reflective interface between the plastic and the water. The distortion of the mirror is detected by means of a scanning focused laser beam, and the angle of reflexion of this beam is caused to vary periodically by the ripple pattern at the acoustic frequency and in proportion to the local sound pressure amplitude³. An electrical signal, coherent with the sound pressure, is produced in a photodiode which intercepts half of the beam, the other half being obscured by a knife edge. This signal is amplified, filtered, amplitude- or phase-detected, and fed to a TV monitor which displays either an acoustic image or an acoustic hologram of the specimen. The TV monitor is synchronized to the scanning laser beam and the system operates at standard TV rates, that is, the frame time is 1/30 s.

To display an optical picture simultaneously, the plastic mirror is made semi-transparent, thus allowing a fraction

of the scanning beam to penetrate through the sample. The light transmitted through the specimen is collected by a separate photodiode and the resulting electrical signal is displayed on a second TV monitor. Thus, the optical and acoustic images appear simultaneously on the two monitors and are in register.

A schematic diagram of the sound cell is shown in Fig. 1. Its function is to couple acoustic energy to the specimen at the desired angle of illumination and to mechanically support the specimen parallel to and in close proximity to the face-plate. In this manner the detector plane, the mirrored surface, is in the near field of the sound image. Instead of a simple water path coupling from the transducer to the specimen as described previously¹, a fused quartz block is used here to avoid losses due to acoustic absorption. Although the sound beam strikes the quartz-water interface at an angle of 45° , it is refracted into the water at 10° owing to the difference in sound velocities. Sound which is scattered by the specimen between the angles of 0° and the critical angle of 43° for the polycarbonate used is electronically selected and fed to the TV monitor. The minimum resolvable detail is about $20\text{ }\mu\text{m}$, which is equivalent to $f\text{ }1.3$, confirming calculations based on the effective numerical aperture. This aperture is determined by the critical angle of incidence at which the interface appears infinitely rigid and thus, the response drops to zero. Other solid materials which could also serve as a mirror generally have greater velocities of sound than does polycarbonate, resulting in a smaller value for the critical angle, narrower angular field of view and, hence, poorer resolution than $20\text{ }\mu\text{m}$ for the same frequency. The measured sensitivity is of the order of 10^{-3} W/cm^2 and may be further improved by increasing the frame time or the laser power as described earlier².

Fig. 2 shows the acoustic (*b*) and optical (*a*) images of the live larva of the fruit fly *Drosophila melanogaster*. Each TV monitor displays an area of $1.7 \times 1.2\text{ mm}$ and, since the animal was considerably longer than the uniform region of the sound field, it was necessary to image only one section at a time. About 40% overlap has been provided, however, for better continuity between frames. The optical image is dark field, produced by slightly offsetting the appropriate photodiode so as to not receive the unscattered light from the specimen.

There are a number of interesting features displayed in this figure. Most of the fine line detail in the acoustic image represents the tracheal network branching out from two main tracheas which are visible in both images and run the entire length of the animal. In retrospect it could have been expected that these air interfaces would show up well acoustically since the mechanical impedance mismatch is great. The head of the larva is located on the right and the foremost dark structure (acoustically and optically) is the mouth. About one-third the way down from the head (about centered on the second strip from the right) is an acoustically opaque region about $200\text{ }\mu\text{m}$ in diameter which is probably

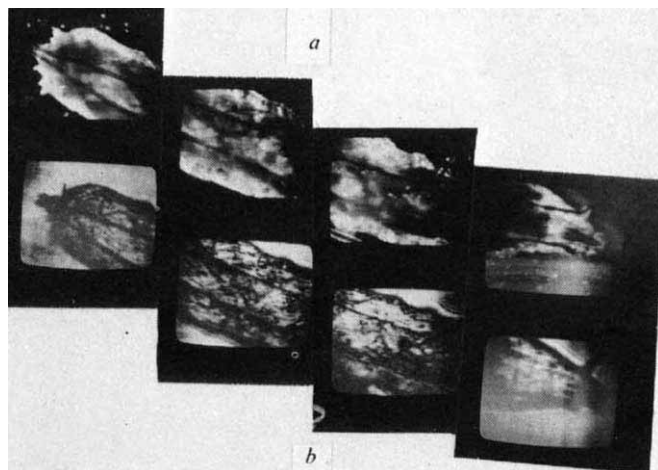


Fig. 2 *Drosophila melanogaster* larva. *a*, Optical image; *b*, acoustic image.

the proventriculus. This organ functions as a "pre-stomach" into which the food passes before entering the stomach (midintestine). Why is the proventriculus so clearly visualized with sound, whereas the other parts of the alimentary tract such as the intestine and oesophagus are not? The reason is that the proventriculus, unlike the other organs, possesses an inner layer with a chitinous intima⁴, a material also found in the shells of mollusks. Apparently, the acoustic impedance of this chitinous substance differs greatly from that of the surrounding tissue. The total absence of this structure in the optical image is a result of overall optical opacity. The hind two-thirds of the larva is also detailed with trachea and other structures which have not yet been interpreted.

At 100 MHz the loss in acoustic amplitude owing to absorption in small tissue structures of the order of $25\text{ }\mu\text{m}$ diameter, is insufficient to cause observable contrast. A significant feature of acoustic microscopy at this relatively low frequency is that certain tissue interfaces exhibit far greater contrast acoustically than optically. At still higher acoustic frequencies, up into the low GHz range, the acoustic absorption will greatly increase, which may make it possible to make visible otherwise undeterminable parameters such as *in vivo* microviscosity and macromolecular conformation⁵. The magnitude of the ultrasonic absorption is sensitive to macromolecular conformational changes over the 1–100 MHz frequency range. A relaxational contribution, in which the acoustic wave perturbs the statistical distribution of molecules among the possible conformational states, does not appear to be as important as the non-relaxational absorption caused by the viscosity characteristic of one or the other state. Because the resolution in that frequency range becomes comparable with that of an optical microscope, the range of application of acoustic microscopy will be greatly increased over that of the present 100 MHz device.

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- 1 Korpel, A., Kessler, L. W., and Palermo, P. R., *Nature*, **232**, 110 (1971).
- 2 Korpel, A., and Kessler, L. W., *Acoustical Holography* (edit. by Metherell, A. F.), **3**, ch. 3 (Plenum Press, New York, 1971).
- 3 Whitman, R. L., and Korpel, A., *Appl. Optics*, **8**, 1567 (1969).
- 4 Bodenstein, D., in *Biology of Drosophila* (edit. by Demerec, M.), **275** (Hafner, New York, 1965).
- 5 Kessler, L. W., and Dunn, F., *J. Phys. Chem.*, **73**, 4256 (1969).

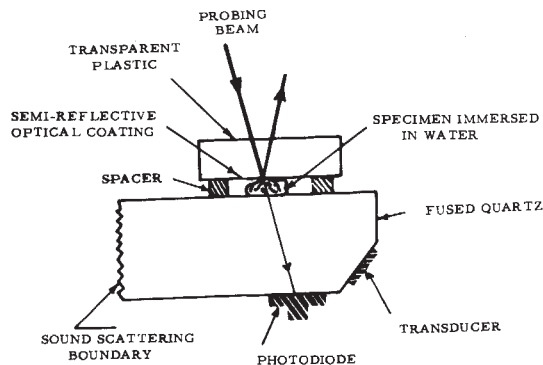


Fig. 1 Sound cell (10° acoustic illumination).

BOOK REVIEWS

Reciprocity

The Human Agenda. By Roderic Gorney. Pp. 698. (Simon and Schuster: New York, 1972.) \$12.95.

It has been said that the only philosophically tenable position for a pessimist in a time of crisis is optimism . . . an "as if" fiction, that if a sufficient number of us will do what we ought, we may yet save the human enterprise. Pessimism is a condition that mostly affects those who were idealists in their youth; accidie not infrequently turns it into cynicism. Being human is, perhaps, the most difficult of all accomplishments, largely because what it means is so little understood. Theories of the nature of human nature are as numerous as the proverbial leaves in Val-lombrosa, and as impermanent. In this massive book, by a young psychiatrist, the leading contemporary theories concerning the nature of human nature, those of Ardrey, Lorenz, Freud, Fromm, Marx, Darwin, and others, are subjected to a careful critical examination in the light of evidence drawn from many different sources. The conclusion at which Dr Gorney arrives is not new, but it is drawn so convincingly I do not see how it can be seriously challenged. As he reads the evidence it is clear to the author that cooperation, not competition, is the central law of life, and that man's development of his value systems constitutes an adaptive response to the requirements of this law.

Cooperation is, of course, a characteristic of all living organisms, even though the German embryologist Roux, many years ago attempted to show that competition was the rule even among cells. His view seems to have been more congenial to the intellectual climate of his day than that of the French polymath Espinas who, in his remarkable book *Des Sociétés Animales*, published in 1878, presented the case for cooperation, "habitual reciprocity", as the much neglected principle in the evolution and maintenance of animal societies. Competition, ever since Hobbes's *Leviathan* (1651), has had a far greater appeal than the idea of cooperation, and for obvious reasons. *Mutual Aid* (1902), Kropot-

kin's reply to Huxley's muscular Darwinism, has not been as widely read as the works of Robert Ardrey and Konrad Lorenz, even though it is at least as readable and a great deal sounder than the writings of these authors on the innate depravity of man. Dr Gorney discusses the works of all these writers, and he does so most effectively, bringing a wide and varied range of knowledge to bear on the analysis of their ideas.

Resumed in a few words, what is the human agenda? It is to learn to live as if to live and love were one, to develop those three chords of mental health: the ability to love, to work, and to play . . . to die young—late.

In a short review it is impossible to do justice to this stimulating work. Suffice it to say, then, that it is in the best tradition of American humanistic thought.

ASHLEY MONTAGU

Man Midwife

Hunter's Lectures on Anatomy. Pp. 320. (Elsevier: Amsterdam, London and New York, 1972.) Dfl. 35; \$10.25.

THIS book has a curious history. Two manuscript notebooks containing forty-eight lectures entitled *Hunter's Lectures of Anatomy* came up for auction together with other old medical books in Adelaide, South Australia, in 1959. They were bought by Miss Nell Dowd, a lady of discernment, who, having established that they were the lecture notes of Dr William Hunter (1718–1787), set about tracing their recent history. She found that the previous owner had visited Manchester in 1905 where she had been given a box of old medical books, all of which had previously belonged to Dr Charles White (1728–1813). These books remained untouched until they came up for auction more than 50 years later. Miss Dowd then found that White had attended Hunter's lectures in 1748. Thus, with scholarly exactitude she established beyond doubt that Hunter's lecture notes had been transcribed by Charles White. Unfortunately she did

not pursue her research any further. Nor did she edit the text, reproduced here in its original copperplate script. Although she may not have felt competent to undertake such a task herself it would not have been too difficult to enlist the cooperation of a medical historian, as both master and pupil deserve a biographical outline at least.

After attending the Edinburgh lectures of Alexander Munro primus, William Hunter came to London where he assisted Smellie while studying surgery at St George's Hospital. After rounding off his postgraduate training during a winter in Paris followed by a tour of Holland, Hunter began teaching surgical anatomy in 1746 from his Covent Garden residence. Two years later his students included his younger brother John and Charles White. On his return to Manchester, White gained a reputation in obstetrics, eventually being given the quaint title of "Man midwife extraordinary". He pioneered aseptic midwifery in order to control the high mortality from childbed fever, and his observations entitled "Treatise on Management of Pregnant and Lying-in Women (1773)" preceded Semmelweis's work in Vienna by 75 years.

In his lecture notes Hunter gave an outline of systematic anatomy, or rather surgical anatomy, as anatomical details are enlivened with interesting clinical or historical asides. When discussing the anatomical relation of the uterus, Hunter points out "how Calamitus a Circumstance it is for a Woman with Child, to have a Stone in the Bladder as from the Situation of the Stone, the Child's Head must press against it". And when describing the anatomy of the spleen he mentions the case of the guardsman wounded at the battle of Dettingen who "laid all night in the Wet and the Spleen protruding thro' the Wound was mortified and mostly cut away not wthstanding wch the man is now living" (1752).

One of the most controversial issues in this notebook concerns the discovery of the lymphatic system. The brief but accurate description contained in this notebook of 1752 (without any reference to Munro) would substantiate Hunter's claim which was later supported by

thirteen letters from former pupils who had attended his lectures.

These notebooks implement our knowledge of William Hunter as the foremost teacher of surgical anatomy of his time. His reputation also rests on his immense contribution to midwifery and the assembly of a vast museum of surgical anatomy. This elegantly produced book, with a foreword by Sir Charles Illingworth, would have enhanced his reputation further had it been fully edited, preceded by a biographical introduction and set firmly within the historical context of his times.

KENNETH DEWHURST

Particles in the Air

Assessment of Airborne Particles: Fundamentals, Applications and Implications to Inhalation Toxicity. Edited by Thomas T. Mercer, Paul E. Morrow and Werner Stöber. (A Proceedings Publication of the Third Rochester International Conference on Environmental Toxicity.) Pp. xix+540. (Charles C. Thomas: Springfield, Illinois, March 1972.) \$23.75.

THE twenty-seven papers of this volume were presented at a conference held in June 1970 at the Department of Radiation Biology and Biophysics of the School of Medicine and Dentistry, University of Rochester, New York. Five sessions covered aerosol fundamentals, production and measurement of aerosols, size analysis and shape factors, inhaled aerosols and the assessment of hazardous aerosols. There are good author and subject indexes and the book is well produced.

Papers in the first session dealt with the enhancement of rate of coagulation due to polydispersity, the deposition of particles from turbulent flow in a wind tunnel upon artificial grass, impaction of particles upon wires coated with adhesive, the collection efficiency declining as the adhesive became covered with particles, a study of membrane filtration and a survey of existing knowledge of the atmospheric aerosol. The general conclusion is that the size distribution of atmospheric particles is not self-preserving as a result of a balance between generating and eliminating mechanisms—because the residence times of particles are too short—but that it is a reflexion of the action of various sources of aerosols.

An alternative to counting aerosol particles is to form a jet surrounded with clean air which is directed towards a microscope objective so that lateral displacements can be accurately measured. Thermophoresis and diffusio-phoresis of the particles can be

measured. Variation of the supersaturation of the clean air sheath makes it possible to study the formation of visible aerosol upon condensation nuclei in the aerosol jet.

The session on production and measurement of aerosols included descriptions of three new thermal generators. One used helium as a carrier gas, with nuclei of sodium chloride, and evaporated the aerosol material from a film of liquid running down the inside wall of a vertical tube; another made an aerosol of solid particles of carnauba wax and the third employed high frequency induction heating to generate silver aerosols having diameters between 0.002 and 0.1 μm . Size analysis by light scattering and diffusion, the growth of particles by condensation and a dust generator were also discussed.

Papers on size analysis and shape factors covered automation and the use of fibre optics for scanning projected areas. There was a study of mechanical size separation and an aerosol spectrometer working by sedimentation into a stream of clean air adjacent to the sampled aerosol was described in detail; it was applied to industrial dusts, including asbestos fibres, and to testing size-selecting samplers and filters.

Two papers on shape factors were based on experiments with a spiral centrifuge aerosol spectrometer; one dealt with latex sphere aggregates and fibres and the other with dusts of coal, UO_2 and ThO_2 .

Inhaled aerosols were the subject of calculations to try and show the differences in deposition between spheres and ellipsoids and the retention of insoluble particles in animals of different species in terms of lung clearance and storage in the tracheobronchial lymph nodes. Calculations were also presented which were aimed at finding the effects of zero gravity and of hygroscopic particles. Experiments in human breathing of 0.5 μm diameter particles showed that deposition decreases when the reserve volume is raised. The inhalation of dust from polyurethane foam was found to produce carcinoma in rats. Experiments with various kinds of asbestos fibres indicate that the sedimentation rate depends mainly on fibre diameter, and when this exceeds 3 μm penetration to the alveolated regions of the human lungs is improbable unless the fibres are open, fluffy bundles of fibrils which have a low sedimentation rate.

The last session of the conference covered sampling methods for use in occupational hygiene. Selective sampling is achieved by cyclones in a two stage device which can be matched to deposition in the mouth or nose and in the tracheobronchial regions; another device uses a cyclone followed by a bubbler which was believed to match alveolar deposition. The preparation of

filters from aluminium oxide which have a pore size of 0.025 μm is described; they withstand temperatures up to 700° C so that dust deposits can be incinerated. By using these filters in mines it was shown that fine dust below 1 μm diameter does not contribute appreciably to the mass of the respirable fraction (50% cut at 5 μm) but that it accounts for some 20% of the surface area.

The remaining two chapters deal with the sampling of urban aerosols and of viable particles. The former is a plea for a less general approach to the formulation of quality criteria and the latter describes the microthread technique for obtaining a "captive aerosol" and the disclosure of an atmospheric factor toxic to microorganisms which it has led to.

C. N. DAVIES

Statistics in Russian

Russian - English / English - Russian Glossary of Statistical Terms. By Samuel Kotz. Based on *A Dictionary of Statistical Terms* by M. G. Kendall and W. R. Buckland. Pp. vii+87. (Edinburgh: Oliver and Boyd, 1972.) £3.

THIS dictionary was originally envisaged as a sixth volume to the combined foreign-language glossary in the now standard *Dictionary of Statistical Terms* of M. G. Kendall and W. R. Buckland; however, in the course of compilation it developed into a new and valuable work in its own right.

Unlike the best-known existing statistical glossaries for Russian, this volume contains both Russian-English and English-Russian sections, the latter containing some 2,500 terms, the former being somewhat larger. Thus, although it will prove more valuable to the western reader wishing to read Russian statistical material in the original, the English-Russian section is sufficiently comprehensive for the purposes of the English-speaking statistician who may need to write an occasional letter in Russian to a colleague or library in the Soviet Union, asking, say, for additional material in a given field. It would probably not, however, be sufficient for the compilation or translation of scientific papers into Russian, although it would, again, prove useful for the writing of the Russian-language abstract now so often required for international conferences.

Russian statistical vocabulary differs somewhat from English, and some terms have no exact equivalent. Thus, on a single page (p. 82) we find five terms (Sturges's rule, sub-normal-dispersion, substitute F-ratio, superfluous

variable and super-normal dispersion) which require a periphrasis or additional explanation in Russian. The author deals with these difficulties in a competent manner, reducing such explanations to a minimum, and without straying into unnecessary digressions.

Statistical vocabulary is a particularly difficult field for the lexicographer dealing with Russian. Professor Kotz has solved the problem in a generally competent manner, concentrating on a readership of professional statisticians, and omitting those terms which belong to general mathematics rather than statistics. The user is clearly assumed to have a good knowledge already of the Russian language; no grammatical indications, such as the gender of nouns or the paradigms of irregular verbs, are given. It is not a book for the beginner, either in statistics or in Russian. For the Russian-speaking statistician, however, who requires a useful compendium of the most commonly used statistical terms in a relatively compact form, it should prove a most valuable addition to his working library.

VERA RICH

Plant Morphology

Shoot Organization in Vascular Plants. By K. J. Dormer. Pp. 240. (Chapman and Hall: London, March 1972.) £4.50.

THIS book is not primarily about morphogenesis, as the title might lead one to think, but more about the morphology of the mature angiosperm primary shoot. The author has "tried to set down some of the more widely applicable principles governing the growth and behaviour of the shoot system" as illustrated by selected examples, with quantitative data where possible. The examples are all examined critically, often at length. The book is aimed at advanced and postgraduate students.

The author excludes consideration of the early stages of development from the meristem and excludes almost all, except simple, experimental work. This approach results in the first chapter, on "the initiation of new shoots", being almost entirely about the regeneration of plantlets on mature leaves. The initiation of shoots from axillary buds or cultured tissues is ignored. The chapter on the measurement of growth is perhaps the best part of this book. The common types of growth curves are clearly explained and the value and limitations of the plastochron index as a developmental time scale are carefully examined. Other chapters cover some aspects of the later stages of leaf

development, the measurement of phyllotaxis, heteroblasty in leaves, the structure of the primary vascular system, and asymmetries such as anisophylly and unequal buds. In considering "the shoot system in its environment" the author rightly points out that the effects of mechanical stress on morphology have tended to be neglected, and he gives some examples of these effects. Gravimorphism in trees, however, is ignored. There are other gaps. There is virtually no mention of apical dominance, and very little about plants showing secondary growth, or about the effects of growth substances on morphology. The author seems to have been too often at pains not to "follow the fashion" and to have included material simply because it has not appeared elsewhere. It is otherwise difficult to see why some poor data are included (as in the lengthy discussion devoted to epidermal cell lengths in two plants, one etiolated, one not) in preference to much better data which are ignored. Especially in view of the quantitative approach it is disappointing that of the thirty or so graphs only two have units on both axes and that four have neither axis labelled with anything at all.

This book is well produced and singularly free of minor errors. Its value would have been enhanced by reference to topics and papers not otherwise touched on, for, as the author says: "I hope that none will be so misguided as to see in my own imperfect text a substitute for the diligent examination of original papers".

R. F. LYNDON

Revised Relativity

The Theory of Relativity. By C. Møller. Second edition. Pp. xiii+557. (Clarendon: Oxford; Oxford University: London, March 1972.) £13.

READING this book is what it must be like to be conducted through some great forest by a guide who knows every inch of the ground. We soon discover that Professor Møller is quite sure where he is taking us. He may seem to keep leading us into glades and thickets, but every time he gets us to precisely the place where he wants us to be, having skilfully avoided various obstacles on the way. He keeps our feet on the ground and gives us an extensive exploration at that level. He invites us neither to investigate the roots very deeply nor to ascend to the tree-tops whence we might gain a more expansive view—and however precarious that might be, most of us would want to take the risk.

The book may be described as an up-to-date account of "classical" relativity

theory. Almost half of it is a thorough presentation of the special theory. The rest is a careful account of the general theory regarded, naturally, as principally a theory of gravitation. Møller's viewpoint is conveyed by the titles he chooses for his chapters. For example, chapter 10 on particle mechanics, light-propagation, mechanics of continuous media, electromagnetism, in general relativity he calls "The influence of gravitational fields on physical phenomena"; chapter 12 on classical and modern tests of the theory (in the discussion of which Møller has played a leading part) as well as on the rudiments of relativistic cosmology, he modestly calls "Experimental verification of the general theory of relativity. Cosmological problems".

Møller's book is more justly regarded as a book of 1972 than as the re-issue of a book of 1952. An indication of this is the fact that the valuable bibliography, itself a new feature, includes about 100 items that have appeared after the earlier edition was written. Most of the new material is in the part of the book on general relativity; there are critical accounts of such "modern" topics as gravitational radiation and black holes (in particular, the "Kerr solution"). Another innovation is the presentation of some material as "exercises" in the text, mostly with an indicated solution.

Møller still intends his book to be a "textbook for beginners in the field". A beginner would have to be very bright indeed to work through the book on his own, but under the guidance of a knowledgeable teacher he will find it of much value as a textbook and probably even more as a work of reference. In this regard, it will be valued particularly for the wealth of material that is not treated elsewhere at textbook level. Of course, even at that level, Møller has had to exercise much selection so that, merely as examples, he has less to say about the relativistic treatment of "rigid" bodies and of rotating bodies, compared with other topics, than might have been expected. But the book is already half as long again as the first edition, and it is probably best that Møller should have to some degree given more attention to topics that have been of particular interest to him in his long career of distinguished work in relativity. Indeed, the above-mentioned beginner, and all other relativists as well, are fortunate that Møller has provided this substantial and systematic account of his work on so many of these topics. Moreover, it is hard to see how anyone can properly appreciate the motivation of the modern more abstract general formulations of relativity theory without having first mastered much of the material here presented.

W. H. MCCREA

INSTRUMENT REVIEW

Imaging in Astronomy

Spectracon Image Tube (Instrument Technology Ltd, from about £3,000).

In spite of their poor quantum efficiency (at best about 1%) and the non-linearity of their response, photographic emulsions have long been the principal recording medium used by astronomers. But improvements in the manufacture of photocathodes, with peak quantum efficiencies of up to 20%, have led to the development of image intensifiers in which the accelerated photoelectrons are focused on to a phosphor screen. The brightened image is then recorded on a photographic emulsion. Although these tubes can be cascaded into multi-stage intensifiers, the use of a phosphor screen, together with the necessary transfer optical system, does degrade the resolution of the intensifier, and the non-linearity of the photographic emulsion makes it difficult to do accurate photometry over a wide span of brightness levels.

In the 1930s Lallemand demonstrated that the photoelectrons could be registered directly in a nuclear emulsion. As these emulsions are required to record the tracks of particles with energies of several tens of keV, the grain size of the emulsion can be extremely small and the spreading of the image will be determined solely by the projected track length in the plane of the image. Furthermore, the much greater capacity for storing information, and the single-hit nature of the process, mean that this type of recording has a high degree of linearity over a very great range of input brightness levels. Unfortunately the exploitation of this technique, known as electronography, was hampered by the requirement that the nuclear emulsion be inside the evacuated envelope of the image tube, so that the photocathode was destroyed when the plates were retrieved.

J. D. McGee of Imperial College, London, suggested that if the phosphor output window of the normal intensifier was replaced by a thin membrane of mica, the focused photoelectrons would pass through it and could be registered in a nuclear emulsion pressed into intimate contact with the other side of the mica. Repeated exposures would then be possible without risk to the hard vacuum and hence the photocathode inside the image tube. In the tube which McGee developed from this idea, the mica window, for mechanical reasons, is rectangular in shape (25 mm long and 3, 5 or 10 mm wide). The device¹ is therefore most suited to

spectroscopy and was thus named the 'Spectracon'.

Several of these tubes have been distributed to observatories both in Britain and elsewhere. A considerable amount of early work was done with the Spectracon on the 30 inch coude spectrograph of the Royal Greenwich Observatory at Herstmonceux and details of observations using a Spectracon with the Cassegrain spectrograph on the 36 inch telescope at the Royal Observatory, Edinburgh, have also been published. More recently two Cassegrain spectrographs designed around the Spectracon, have been built at Herstmonceux and are now in use on the 74 inch Radcliffe telescope at Pretoria and on the Isaac Newton telescope². Results have shown that measures of radial velocities made with the Spectracon are as precise as those obtained with conventional photography while the overall information gain over the latter is about ten times.

Although the shape and size of the mica window place restrictions on the field available for direct stellar photometry, the linearity of the Spectracon has encouraged several workers to investigate its potential in this respect. So far, the most successful efforts to exploit the tube in this way have been those of M. F. Walker of Lick Observatory, who has used the Spectracon to establish the colour-magnitude diagram of several star clusters in the Magellanic clouds down to limits much fainter than those hitherto attainable³. These and other studies have shown that the Spectracon can yield photometric data, with an accuracy comparable with that of the best photoelectric measurements, over the whole area of the mica output

window. Under suitable conditions the extremely low background levels suggest that objects can be detected which are between 2 and 5 magnitudes fainter than may be detected photographically with the same exposure time. This, together with the much greater range of magnitudes that can be recorded in a single exposure and the ability to distinguish faint objects against the sky background more readily, indicates how powerful a tool the Spectracon is.

Several observing programmes in field photometry are now in progress in addition to Walker's. These include direct electronography of radio galaxies both in emission lines and continuum (joint programme between Imperial College and the Radio Astronomy Group in Cambridge), of planetary nebulae (Imperial College) and of Seyfert galaxies (Cambridge Observatories).

The most serious problem in using electronography arises when it comes to reducing the observations. In spectroscopy, conventional visual measuring techniques are not satisfactory because of the low contrast at normal working densities and the maximum information can only be obtained by the use of photoelectric scanning or grain counting techniques. In the case of direct field photometry, the amount of information present on a single electronograph can be quite staggering, and great care must be taken to preserve the linearity of the record during the microphotometry process. For many purposes conventional microphotometers are adequate—Walker used one dimensional scans of the stars he studied—but for the highest accuracy two dimensional scans are necessary. The development of very fast two dimensional microphotometers is now allowing considerable progress to be made. For some applications it may be necessary to calibrate out the variations in sensitivity over the photocathodes.

From the astronomer's point of view the Spectracon is a fairly simple device to use, although the tubes clearly require greater care in handling by comparison with photographic plates. The tube requires stabilized power supplies to provide the e.h.t. voltage (40 kV) and focus coil current. Some form of cooling of the solenoid is necessary, usually by recirculating refrigerated coolant, although more recently this has been dispensed with for work at the telescope prime focus by using single loop focusing in conjunction with Peltier cooling of the photocathode. Spectro-



Part of the field of the radio galaxy C3 449 taken with a Spectracon image converter made by J. D. McGee. The exposure was for 60 min through a V-filter on the 98 inch Isaac Newton telescope at Herstmonceux. Objects in this field which are at the limit of the National Geographic-Palomar Sky Survey are detected with a signal to noise ratio of about 20.

scopists have taken advantage of the ability to use electronic scanning to broaden stellar spectra and for this a suitable generator is necessary. Scanning techniques can also be used in both spectroscopy and field electronography to detect variability in stellar objects. The nuclear emulsions are developed in the same way as conventional photographic materials although dust problems appear to be more acute. Ilford G5 and L4 are the two emulsions normally used. G5 is the faster and can be used where positional information is the main requirement. For optimum photometric linearity and noise performance, however, the slower, finer grained L4 material is to be preferred. Provided care is taken that no sharp particles of dust are present on the emulsion before it is pressed against the output window, there is little risk of rupturing the mica. Once the vacuum

seal is broken, however, the tube cannot be repaired.

The considerable interest in the Spectracon prompted the British Science Research Council to sponsor the commercial production of the device by Instrument Technology Ltd. So far ITL have produced several standard tubes with S11 (blue sensitive) photocathodes and windows 5 mm wide, but they hope to eventually market Spectracons with wider windows (10 mm) and/or S20 (blue and red sensitive) photocathodes. These first tubes are being subjected to laboratory tests at the Royal Greenwich Observatory and the results show that ITL Spectracons are likely to be of generally high quality. Initial observations with one of them, now at Pretoria, confirm this.

The relatively modest cost of purchasing and running a Spectracon image tube will allow even relatively small

observatories to make their observations more rapidly and with much greater precision. With a large telescope in a good climate it will undoubtedly be possible to record objects fainter than have been seen already. The considerable gains achieved by using this device more than offset the slight adjustments that the astronomer must make to his observing routine, and the more widespread use of the Spectracon must clearly be encouraged.

C. D. MACKAY
A. S. MILSOM

¹ McGee, J. D., McMullan, D., Bacik, H., and Oliver, M., in *Adv. Electronics Electron Phys.*, **28**, A, 61 (Academic Press, London, 1969).

² Palmer, D. R., and Milsom, A. S., in *Adv. Electronics Electron Phys.*, **33** (in the press).

³ Walker, M. F., *Mon. Not. Roy. Astron. Soc.*, **156**, 459 (1972).

CORRESPONDENCE

British Optical Astronomy

SIR,—There has been considerable comment in the press and in editorials in *Nature* and elsewhere concerning the resignation of Sir Fred Hoyle from the Plumian professorship at Cambridge and the circumstances which led up to this disaster for British astronomy. As a close scientific colleague and friend of his, resident in the US, and as an Englishman who is familiar with the international as well as the parochial British astronomical scene, it seems to me that it is time to share a few home truths with your readers and discuss what, if anything, can be done to improve the situation.

While radio astronomy and theoretical astronomy are in reasonably good shape in the UK, optical astronomy as it is being currently practised in the British Isles is only third rate. Why is this? It is primarily because the British astronomical establishment has consistently, over the period since the war, refused to face the real world or accept that anything was the matter, and when important decisions were made, they were either hopelessly wrong or too late or both.

Key mistakes include:

1. The siting of the Isaac Newton Telescope—the biggest British telescope—in the UK, making it almost completely useless.

2. The refusal of the British to join in the European Southern Observatory (ESO) project. The Europeans, as well as two groups from the US, one from Canada and one from the USSR, are

currently building observatories in northern Chile which has the best astronomical climate so far discovered in the world.

3. The decision to build a large telescope in Australia jointly with the Australians without proper consideration of the observing conditions in Australia or outside.

4. The footdragging involved in the creation of the Institute of Theoretical Astronomy in Cambridge, proposed at least eight years before it finally appeared. This was largely a Cambridge mistake, and of course there has been continuous sniping at it, largely from Cambridge, ever since it was created. In the new arrangement which started on August 1 the character of the Institute has been changed for the worse.

5. The decision to build a large Schmidt telescope in Australia without appearing to know or care that it is being put on an inferior site and that the ESO group will have a similar telescope operating in Chile this year.

6. The refusal of the Science Research Council to implement or even to publish the findings of the Northern Hemisphere review committee in which a majority recommended two years ago that a modern National Centre for optical and infrared astronomy be set up to run the overseas ventures.

7. The appointment at Cambridge, as a successor to R. O. Redman, himself an observational astronomer, of a person totally unqualified in this field. This led to Sir Fred's resignation.

8. The diversion of much talent and money into the design and development of equipment which is then used not as a tool to do astronomy with but as an end in itself. The much vaunted Galaxy machine may now be coming into use but it has been inordinately expensive in time and money and there is no great demand for it outside the UK, nor is there any assurance that it will lead to great advances in astronomy.

Clearly many apologists will clamour to refute these statements, but those who are primarily interested in science will accept the validity of everything that has been stated.

Over the years Hoyle, England's most creative astronomer in many decades, has attempted to improve the situation. He and some others, particularly Sir Bernard Lovell, have, to my own personal knowledge, attempted to reverse the trend from almost complete to absolute mediocrity. Some of us have tried, peripherally, to help. We have so far failed.

What, if anything, can be done to retrieve the situation? The only hope would appear to be the creation of a new group or organization with an international background which will set itself the single goal of creating somewhere in the world an optical observatory which, as far as climate and instrumentation are concerned, is second to none. Such an institution must have a parent organization in England, but it must be international

in outlook and probably also in staff, at least to start with. For it must be grasped that, much as the British prefer themselves to foreigners, foreigners, and particularly Americans, lead in this esoteric field. The expatriate British observers, who are prominent in the US and in South Africa, should be invited to become involved despite their almost universal dislike of the pettiness of English astronomical politics, and their strong attachment to clear skies, warm climates, and in some cases high salaries, and their perversity in wanting to investigate the universe rather than talk about it. The observatory should be built on the shortest possible time scale—five years is entirely possible—in Chile where the climate is guaranteed, or possibly in Southern Spain, the Canary Islands, Baja California or the south-west US. Many of us know that it is possible to collaborate and co-operate with the Americans, the Chileans, the Germans, the Spaniards or the Mexicans, and we relish the opportunity of trying. The major telescope should have an aperture ≥ 90 inches, should be built on a proven design and should contain no British, and hence unproven, astronomical innovations. Technical expertise should be encouraged.

Give a few young and active British astronomers, who want to find out, access to such an observatory, and in my opinion the attitudes will change overnight.

Margaret Burbidge, who has just arrived at Herstmonceux, is strongly behind such an idea, but she and others who would like to do this are terribly vulnerable. It will be so easy to talk this proposal to death or worse still to decide to build a telescope on a peculiarly British site (the Rock of Gibraltar?) and a British time scale (21 years for the INT) with a newly designed British mounting and even with a revolutionary mirror design. This is what we can expect if the old system of SRC planning committees, instrumental committees and never-ending consultations with everyone is adhered to. It has long been understood by those who successfully build major instruments, be they big accelerators or large optical or radio telescopes, that the only successful way to operate is by the appointment of a governing board or committee and of a project director (who may well be promised the observatory directorship) and who has authority delegated to him by the board over all phases of design, construction and site selection. He must be able to hire his own staff, again subject to approval by the board.

I have come a long way from the discussion of Hoyle's resignation. But it is clear to me that the circumstances of his departure from Cambridge

should signal the end of attempts to build on the old system. We can try something new like this, but if rapid progress along these lines does not take place, I for one would strongly advise the Science Research Council to save its money. Enough has been wasted already.

Yours faithfully,

GEOFFREY BURBIDGE

*Department of Physics,
University of California, San Diego,
Post Office Box 109,
La Jolla, California 92037*

Taxonomy in Distress

SIR,—It should perhaps be pointed out that it is not only insect taxonomy which is in trouble (*Nature*, 238, 475; 1972); the story can be repeated in other fields. A series of major ornithological collections have been allowed to go abroad—the Gould Collection in the last century, the Rothschild Collection before the war, most of the Hewitt Collection within the last few years, among others. The transfer of the birds in the national collection to Tring (*Nature*, 221, 1094 and 1177; 1969) proves not only to have rendered them inaccessible to most people, but to have brought all work on them to a halt indefinitely. Could we perhaps be informed when the collection is going to be available again, and what arrangements have been made to facilitate work on the fossil bird collection now that the recent comparative material has been transferred elsewhere? It seems time that more consideration was given to whether any work will be done behind the excessively expensive ornament adorning the entrance to the new department foisted on us in such an arbitrary manner.

Yours faithfully,

W. R. P. BOURNE

*The Seabird Group,
Zoology Department,
Tillydrome Avenue,
Aberdeen AB9 1A5*

Lugworm Wronged

SIR,—I would like to correct any impression given by your report on the recent Challenger Society Meeting at the University of East Anglia (News and Views, *Nature*, 238, 131; 1972) that lugworm (*Arenicola marinus*) prey on whiting (*Merlangius merlangus*). In fact the reverse is true. Moreover I claim only that whiting eat lugworm when the latter are used as bait, or are injured, as intact animals are seldom found in whiting stomachs.

Yours faithfully,

M. G. PAWSON

*Ministry of Agriculture, Fisheries and Food,
Fisheries Laboratory,
Lowestoft, Suffolk*

Announcements

University News

Professor Arthur Whiteman has been appointed to the chair of petroleum geology at the University of Bergen.

Professor H. A. F. Dudley, Monash University, has been appointed to the chair of surgery tenable at St Mary's Hospital Medical School, University of London, and **Dr R. Wilson**, SRC, has been appointed to the Perren chair of astronomy tenable at University College London.

Appointments

J. M. Buist of ICI Organics Division has been elected chairman of council of the Institution of the Rubber Industry.

Dr L. S. Renzoni, International Nickel Company of Canada, **R. Thompson**, Dominion Engineering Works, **W. G. Brissenden**, Noranda Mines, and **V. N. Mackiw**, Sherritt Gordon Mines, have been appointed sub-committee chairmen on the National Advisory Committee on Mining and Metallurgical Research of Canada.

The following appointments have been made in the Science Research Council: **Mr J. F. Hosie** as director, administration; **Dr A. W. Lines** as director with responsibility for nuclear physics and engineering; **Mr M. O. Robins** as director with responsibility for the Astronomy, Space and Radio and Science Divisions; **Mr A. J. Egginton** as head of the Engineering Division; **Dr H. H. Atkinson** as head of the Astronomy, Space and Radio Division; **Mr I. A. Learmouth** as head of the Nuclear Physics Division; **Mrs J. O. Paton** as head of the Science Division.

Miscellaneous

Professor Thomas K. Sherwood, University of California at Berkeley, has won the 1973 E. V. Murphree award in industrial and engineering chemistry, which is sponsored by the Esso Research and Engineering Company.

Professor Stanford Moore and **Professor W. H. Stein**, Rockefeller University, have been jointly awarded the third Linderström-Lang gold medal and prize of 15,000 Danish kroner, in recognition of their contributions to protein chemistry.

Erratum

IN the article "Circadian Variation of RNA in Human Leucocytes", by William C. Kohler, Ismet Karacan and Owen M. Rennert (*Nature*, 238, 94; 1972), the second sentence of paragraph 2 should read "A diurnal variation in the number of circulating leucocytes in man has

previously been reported, but up to this point there have been no reports of investigations dealing with periodic RNA changes in human leucocytes". In line 3 of paragraph 9, the word "torula" should read "torula", and in line 3 of paragraph 11, "absorbance at 260 nm" should of course read "absorbance at 260 nm".

International Meetings

October 2, **Luminescence Methods in Physical Biochemistry**, Loughborough (Dr J. N. Miller, Department of Chemistry, Loughborough University of Technology, Loughborough, Leicestershire LE11 3TU).

October 2-4, **Distribution and Partition of Trace Elements and Origin of Volcanic Rocks**, Newport, RI (American Geophysical Union, 1707 L Street NW, Washington DC 20036, USA).

October 2-5, **Yeast Protoplasts**, Salamanca (Departamento de Microbiología, Facultad de Ciencias, Universidad de Salamanca, Salamanca, Spain).

October 2-6, **Environmental Health Aspects of Lead**, Amsterdam (Dr J. Smeets, Health Protection Directorate, Commission of the European Communities, 29 Rue Aldringen, Luxembourg).

October 2-6, **Remote Sensing of Environment**, Ann Arbor (J. J. Cook, Willow Run Laboratories, Institute of Science and Technology, University of Michigan, PO Box 618, Ann Arbor, Michigan 48107, USA).

October 3, **Wear and Its Industrial Implications**, London (Meetings Officer, Institute of Physics, 47 Belgrave Square, London SW1X 8QX).

October 3, **Filter Media**, Manchester (Hon. Secretary, Filtration Society, 1 Katharine Street, Croydon CR9 1LB).

October 3-4, **New Flexible Polymers and Cross Links**, London (The Assistant Secretary, Society of Chemical Industry, 14 Belgrave Square, London SW1X 8PS).

October 3-4, **The Aquatic Environment: Microbial Transformations and Water Quality Management Implications**, Washington DC (L. J. Guarraia, Fresh Water Pollution Control Section, Water Quality Protection Branch, Water Quality and Non-Point Sources Control Division OWP, EPA Washington DC 20460, USA).

October 3-5, **Dietary Lipids and Post-natal Development**, Milan (Miss Hasel J. Prain, Institute of Pharmacology and Pharmacognosy, University of Milan, Via A. Del Sarto 21, 20129 Milan, Italy).

October 3-5, **Choice of Ironfoundry Melting Plant**, Keele (L. J. Stewardson,

British Cast Iron Research Association, Alvechurch, Birmingham B48 7QB).

October 3-6, **Trends in Physics**, Wiesbaden (Secretariat EPS—Conference 1972, D-6000 Frankfurt (Main) 1, Robert-Mayer-Strasse 2-4, Federal Republic of Germany).

October 4, **Food Product Labels—How and Why**, London (Dr H. Fore, 5 Cumbræ Gardens, Ditton Hill, Surbiton, Surrey KT6 5EL).

October 4-6, **Society for Water Treatment and Examination Meeting**, Harrogate (Hon. Secretary, 69 Disraeli Crescent, High Wycombe, Buckinghamshire).

October 5-6, **The Testing of Polymers for Service**, Buxton (Meetings Officer, Institute of Physics, 47 Belgrave Square, London SW1X 8QX).

October 8-13, **Communication and Transport**, Genoa (Istituto Internazionale delle Comunicazioni, via Pertinace—Villa Piaggio, 16125, Genova, Italy).

October 8-15, **Space for World Development**, Vienna (Michael Sartori, Österreichische Gesellschaft für Weltraumforschung und Flugkorpertechnik, Theresianumgasse 27, A-1040 Vienna IV, Austria).

October 9-13, **Marine Electrochemistry**, Miami Beach (Dr Joan Berkowitz, Arthur D. Little Inc., Cambridge, Massachusetts 02140, USA).

October 9-13, **Reactor Shielding**, Paris (Conference Secretariat, OECD European Nuclear Energy Agency, 38 Boulevard Suchet, Paris 16, France).

October 10-11, **Electrical Variable Speed Drives**, London (Manager, Conference Department, LEE, Savoy Place, London WC2R 0BL).

October 10-13, **Chemiluminescence**, Athens, Georgia (Department of Chemistry, University of Georgia, Athens, Georgia 30601, USA).

October 11-13, **Water Pollution Research Laboratory Open Days**, Stevenage (Director, Water Pollution Research Laboratory, Elder Way, Stevenage, Hertfordshire SG1 1TH).

October 12-14, **The Ontogenic and Phylogenetic Study of the Immune Response and its Contribution to Immunological Theories**, Paris (Dr J. Panijel, See Physiopathologie de l'Immunité, Institut Pasteur, 25 rue du Dr Roux, Paris 15, France).

October 13-15, **From Ovule to Seed: Ultrastructural and Biochemical Aspects**, Siena (Professor G. Sarfatti, Istituto di Botanica, Università, 4 via Mattioli, 53100 Siena, Italy).

October 14-15, **The Histochemical Society Annual Meeting**, Boston (Dr S. I. Zacks, Department of Sick and Injured, Pennsylvania Hospital, Philadelphia, Pennsylvania 19107, USA).

October 16-21, **International Fair and Technical Meetings of Nuclear Industries**, Basel (Secretary NUCLEX 72, PO Box, CH-4021 Basel, Switzerland).

October 17-19, **Cleaning Stainless Steel**, Cleveland (American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania, 19103, USA).

October 17-20, **Optical Society of America Annual Meeting**, San Francisco (Dr J. Quinn, Optical Society of America, 2100 Pennsylvania Avenue NW, Washington DC 20037, USA).

October 18, **Environmental Problems in the Food Industry**, London (Dr Robert Shaw, T. Wall and Sons (Meat and Handy Foods) Limited, Atlas Road, Willesden, London NW10).

October 19, **Institution of Mining and Metallurgy Meeting**, London (M. J. Jones, Institute of Mining and Metallurgy, 44 Portland Place, London W1N 4BR).

October 19, **Non-Prescription Antibiotics in Animal Food Stuffs: their Nature and Analysis**, London (Society for Analytical Chemistry, 9-10 Savile Row, London W1X 1AF).

October 19-20, **Microbial Food-Borne Infections and Intoxications**, Ottawa (Mrs E. A. Leduc, Health Protection Branch, Department of National Health and Welfare, Tunney's Pasture, Ottawa, Ontario K1A 0L2, Canada).

October 20-21, **Magnetospheric Substorms**, Houston (American Geophysical Union, 1707 L Street NW, Washington, DC 20036, USA).

October 22-25, **Electrical Insulation and Dielectric Phenomena**, Buck Hill Falls, Pennsylvania (Colonel R. A. Cliffe, NAS, 2101 Constitution Avenue, Washington DC 20418, USA).

October 22-28, **CORESTA/TCRC Conference**, Williamsburg, Virginia (Dr Helmut Wakeham, PO Box 26583, Richmond, Virginia 23261, USA).

October 23-24, **Environment and the Skin**, Cincinnati (Committee on Cutaneous Health and Cosmetics, American Medical Association, 535 N. Dearborn Street, Chicago, Illinois 60610, USA).

October 23-26, **A World of Information**, Washington DC (Robert McAfee jun., ASIS Headquarters, 1140 Connecticut Avenue NW, Suite 804, Washington DC 20036, USA).

October 23-27, **Medical Radioisotope Scintigraphy**, Monaco (IAEA, Kärntnering 11-13, 1010 Vienna, Austria).

October 23-28, **World Congress of Animal Nutrition**, Madrid (Secretaria General, Comandante Zorita 48 2-A, Madrid 20, Spain).

October 24-26, **Computers—Systems and Technology**, London (Conference Department, Institution of Electronic and Radio

Engineers, 8-9 Bedford Square, London WC1B 3RG).

October 24-26, **Computer Communications**, Washington DC (F. M. Trapnell, T. C. Hudson Associates Limited, 28 Crawford Street, London W1H 1PL).

October 25, **Health Hazards in the Iron and Steel Industry**, London (Meetings Department, Iron and Steel Institute, 1 Carlton House Terrace, London SW1Y 5DB).

October 25-27, **Diseases of Vulva and Vagina**, Houston (Office of the Dean, University of Texas Graduate School of Biomedical Sciences at Texas, PO Box 20367, Houston, Texas 77025, USA).

October 26-28, **Wood Preservation**, Berlin (Princes Risborough Laboratory, Princes Risborough, Aylesbury, Buckinghamshire).

October 29-November 1, **Joint Meeting of International Societies for Hygiene, Preventive and Social Medicine**, Vienna (Mrs E. Weidenhaus, Wiener Medizinische Akademie, Stadiongasse 6-8, A 1010 Vienna, Austria).

October 30-November 3, **Microzonation for Safer Construction: Research and Application**, Seattle (Dr M. A. Sherif, Engineering Division, National Science Foundation, 1800 G Streets NW, Washington DC 20550, USA).

October 30-November 10, **Dumping of Wastes at Sea**, London (Department of the Environment, 2 Marsham Street, London SW1).

Reports and Publications

not included in the *Monthly Books Supplement*
Great Britain and Ireland

Universities Council for Adult Education. Report 1970/71. Pp. 20. (Oxford: F. W. Jessup, Honorary Secretary, Universities Council for Adult Education, c/o Department of External Studies, The University, 1972.) [218]

Register of Industries and Colleges in the South West. Pp. 134. (Bristol: The Confederation of British Industry, in association with the University of Bath, 1972.) £2. [218]

Friends of the Lake District. Report and News Letter, August 1972. Pp. 20+6 photographs. (Kendal: Friends of the Lake District, 1972.) [228]

Research Projects and Postgraduate Studentship Studies Sponsored by the Potato Marketing Board—1972 Report. Pp. ii+79. (London: Potato Marketing Board, 1972.) [248]

Medicines Commission. Annual Report for 1971. Pp. 8. (London: HMSO, 1972.) 8p net. [248]

Institute of Coastal Oceanography and Tides, 1971-72. Pp. 43. (Natural Environment Research Council.) (Bidston Observatory, Birkenhead: Institute of Coastal Oceanography and Tides, 1972.) [248]

The Safe Handling and Use of Chlorinated Solvents in Metal Cleaning. Pp. 12. (Hounslow: Dow Chemical Company, 1972.) [258]

Memoirs of the Royal Astronomical Society, Vol. 76, Part 5: Model Atmospheres for DA and DB White Dwarfs. By D. T. Wickramasinghe. Pp. 129-179. (Oxford and London: Blackwell Scientific Publications, 1972. Published for the Royal Astronomical Society.) [258]

Philosophical Transactions of the Royal Society of London. B: Biological Sciences. Vol. 264, No. 861: Lake Sediments in Northern Scotland. By Winifred Pennington, E. Y. Haworth, A. P. Bonny and J. P. Lishman. Pp. 191-294+plate 33. £2.85; \$7.95. Vol. 264, No. 862: Adaptive Radiation and Behaviour of the Malagasy Lemurs. By R. D. Martin. Pp. 296-352+plates 34-38. £1.90; \$5.30. (London: The Royal Society, 1972.) [298]

Proceedings of the Royal Irish Academy. Vol. 72, Section A, No. 8: On the Existence of Weak Solutions for Quasilinear Equations. By T. Karacay. Pp. 109-112. (Dublin: Royal Irish Academy, 1972.) 10p. [19]

Other Countries

Acrida, Tome 1, Fascicule 1. Published quarterly. Pp. 1-78. Library subscription 200 French francs per annum. (Paris: Association d'Acridologie, 105 Boulevard Raspail, 1972.) [218]

International Union Against Cancer. Manual on Volunteer Recruitment. Pp. 23. Manual on Fund Raising. Pp. 60. (Geneva: International Union Against Cancer, 1972.) [218]

India: Council of Scientific and Industrial Research. Science Aids Industry: SCIR in 25 Years of India's Independence. Pp. 27. (New Delhi: Council of Scientific and Industrial Research, 1972.) [218]

International Atomic Energy Agency. The Agency's Programme for 1973-78 and Budget for 1973. Pp. vii+205. Annual Report, 1 July, 1971-30 June, 1972. Pp. 70. (Vienna: International Atomic Energy Agency, 1972.) [218]

World Health Organization Technical Report Series No. 503: Nutritional Anaemias—Report of a WHO Group of Experts. Pp. 29. (Geneva: WHO: London: HMSO, 1972.) 4 Sw. francs; 40p; \$1. [218]

The Cosmic v. By B. Kuchowicz. Pp. 130. (NEIC-RR47.) (Warsaw: Nuclear Energy Information Center, 1972.) [238]

Smithsonian Contributions to Zoology, No. 110: Review of the Genus *Cerceris* Latreille in Mexico and Central America (Hymenoptera: Sphecidae). By Herman A. Scullen. Pp. iii+121. (Washington, DC: Smithsonian Institution Press, 1972. For sale by US Government Printing Office.) \$1.50. [238]

GEOS, Summer 1972. (A quarterly concerned with the earth's resources.) Pp. 16. (Ottawa: The Department of Energy, Mines and Resources, 1972.) [248]

Australia: Commonwealth Scientific and Industrial Research Organization. Division of Land Research—Annual Report 1970/1971. Pp. 101. (Canberra: CSIRO, 1972.) [258]

Directory of Environmental Consultants. Edited by Bill Cate. Pp. 46. (St. Louis, Missouri: Direc-

tory of Environmental Consultants, P.O. Box 8002, 1972.) [258]

US Department of Health, Education and Welfare. National Institutes of Health—Annual Report of International Activities, Fiscal Year 1971. Pp. i+61. Statistical Reference Book of International Activities, Fiscal Year 1971. Pp. 63. (Bethesda, Md: National Institutes of Health, 1972.) [258]

American Medical Association. Statement on Health Planning. Pp. 8. Statement of Multiphasic Health Testing. Pp. 12. (Chicago: American Medical Association, 1972.) [298]

The Israel Academy of Sciences and Humanities. Meteorological Conditions at the Mizpe Ramon Observatory—A Summary of the Climatological Conditions at the Site of the 40" Telescope of the Tel Aviv University. By V. Bar, U. Feldman, A. Kovetz and G. Shaviv. Pp. 10+10 plates. Solar Seeing in Israel and Sinai. By Varda Bar. Pp. 24+18 plates. On the Paleo-Ecological History of the Site of Ubeidiya. By O. Bar-Yosef and E. Tchernov. Pp. 35+5 plates. (Jerusalem: The Israel Academy of Sciences and Humanities, 1972.) [298]

Organization for Economic Co-operation and Development. Science Policy Studies. Analytical Methods in Government Science Policy—an Evaluation. Pp. 89. 9 francs; 70p; \$2. Problems and Prospects of Fundamental Research in Multi-Disciplinary Fields. Pp. 62. 8 francs; 62p; \$1.75. The Research System: Comparative Survey of the Organization and Financing of Fundamental Research. Vol. 1: France, Germany, United Kingdom. Pp. 258. 32 francs; £2.45; \$7. (Paris: OECD; London: HMSO, 1972.) [298]

Publications du Centre National pour l'Exploitation des Océans. Série: Résultats des Campagnes à le Mer. No. 03—1972: Bathyscaphe "Archimède". Campagne 1966 a Mader. Campagne 1969 aux Açores. Pp. 124. (Paris: Centre National pour l'Exploitation des Océans, 1972.) [298]

Medicine and Public Health in the People's Republic of China. Edited by Joseph R. Quinn. Pp. xii+305. (Bethesda, Md: US Department of Health, Education and Welfare, Public Health Service, National Institutes of Health, 1972.) [308]

Reports of the Australian Academy of Science. No. 14: The Use of DDT in Australia. Pp. 72. No. 15: Atmospheric Effects of Supersonic Aircraft. Pp. 48. (Canberra: Australian Academy of Science, 1972.) [308]

Republic of South Africa: Department of Industries. Annual Report of the Division of Sea Fisheries, 1969. Pp. 30. (Sea Point, Cape Town: Division of Sea Fisheries, 1971.) [308]

Canada: Department of Energy, Mines and Resources. Geological Survey of Canada. Paper 72—1: Report of Activities, Part B: November 1971 to March 1972. Pp. v+129. \$2. Paper 72—15: Paleozoic Formations and Silurian Biostratigraphy, Lake Timiskaming Region, Ontario and Quebec. By Thomas E. Bolton and M. J. Copeland. Pp. v+48 (13 plates). \$2.50. (Ottawa: Information Canada, 1972.) [308]

Norges Teknisk-Naturvitenskapelige Forskningsrad. Arsberetning for Budsjettåret 1/1 1971—31/12 1971. Pp. xxxi+264. (Oslo: Norges Teknisk-Naturvitenskapelige Forskningsrad, 1972.) [308]

South African Council for Scientific and Industrial Research. CSIR Research Report No. 309: Algorithm for the Solution of the General Ionospheric Reaction-Rate Equations. By D. G. Torr, D. P. Laurie and M. R. Torr. Pp. iii+4. (Pretoria: South African Council for Scientific and Industrial Research, 1971.) [308]

US Department of Commerce. American National Standard. Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment. Pp. viii+12. (Washington, DC: Government Printing Office, 1972.) 30 cents. [318]

University of the West Indies. Report of the Faculty of Agriculture, 1970/1971. (St. Augustine, Trinidad: University of the West Indies, 1972.) [318]

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